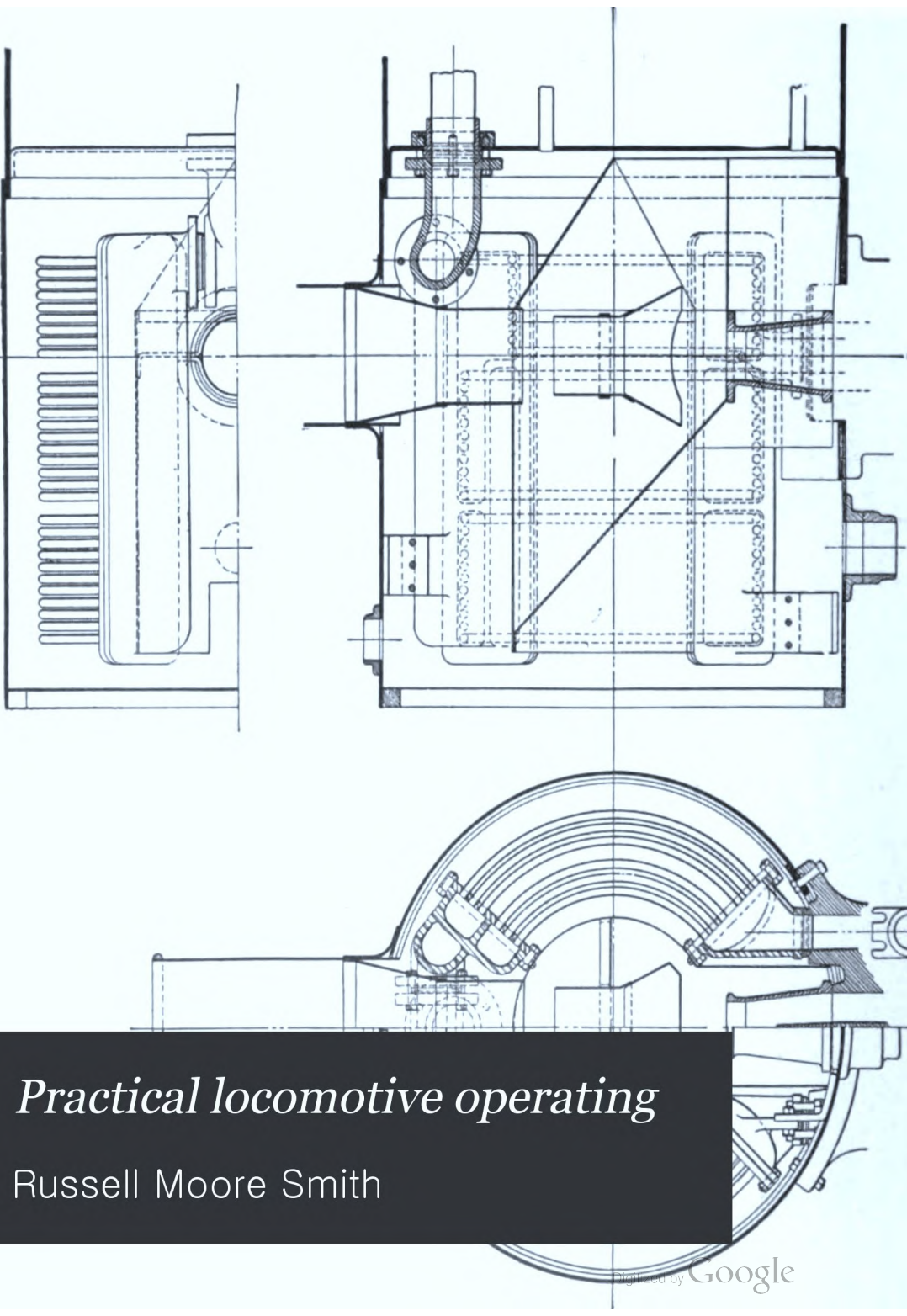

Practical locomotive operating

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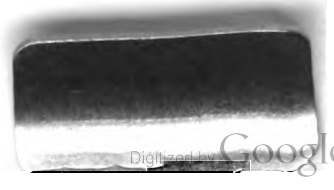
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PRACTICAL LOCOMOTIVE OPERATING

BY

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PHILADELPHIA & LONDON
J. B. LIPPINCOTT COMPANY
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PREFACE

THIS is a locomotive engineers' and firemen's book. Its specialty is the running, firing, and care of locomotives in service. There has been no effort made to present the mechanical features of construction and the details of shop practices in the building and maintaining of locomotives. While a few features are presented in an engineering manner, their purpose is not intended to instruct engineers in the technic of design and proportion, but rather to inform them of the principles involved in the building of an efficient modern locomotive.

Brevity has been adhered to in the presenting of the several subjects, because the spirit of the times demands it, even in the discussing of the most important things. The mathematical formulæ employed and the accompanying examples are also abbreviated, for the process is immaterial, provided the result is correct and is susceptible of easy explanation. This has not been done for the purpose of encouraging engineers and firemen to avoid mathematics or to discard theory, but there seems no good reason why they should be compelled to read through pages of unrelated matter when the desired information can be presented in a few terse and intelligent paragraphs.

No attempt has been made to describe the construction, management, and manipulation of the air-brake, which, although allied to locomotive operating, is comprehensively treated in books devoted solely to that subject. Furthermore, the air-brake is just now in a process of development, and so a treatise here would probably burden the book with matter that will become obsolete in a few years. A few other special appliances are given no place here, that are either in an experimental stage or have but local application, as they in no way affect the general scheme of modern locomotive operating, which is thoroughly explained. If we succeed in making the latter plain to the average engineer, fireman, and aspirant to those positions, our object will be attained.

In the preparation of PRACTICAL LOCOMOTIVE OPERATING, we have

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been furnished cuts of illustrations and made use of literature issued by the following: American Locomotive Company, Baldwin Locomotive Works, Detroit Lubricator Company, Locomotive Superheater Company, Nathan Manufacturing Company, U. S. Geological Survey Bulletins, William Sellers Company.

CLARENCE ROBERTS,
RUSSELL M. SMITH.

PHILADELPHIA, PA., January, 1913.

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PART I

THE LOCOMOTIVE

CLASSES OF LOCOMOTIVES, PROCESSES INVOLVED IN LOCOMOTIVE OPERATING, POWER OF LOCOMOTIVES, TRACTIVE EFFORT AND HORSE POWER FORMULÆ, TRAIN RESISTANCE, EFFICIENCY OF LOCOMOTIVES.

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PRACTICAL LOCOMOTIVE OPERATING

CLASSES OF LOCOMOTIVES.

CONSIDERED from a purely elemental point of view the locomotive is a machine for imparting motion to a train. A steam locomotive is virtually a power plant on wheels, self-contained and complete in detail in its appointments for service requisites. And, as power plants figure, modern locomotives are power plants of no mean proportions, their power capabilities now ranging between 1000 and 2500 horse power.

There are two classes of steam locomotives in general use—viz., the *single-expansion* or *simple* locomotive, and the *compound* locomotive. The simplest form, from which has proceeded practically all development, on the lines of enlargement, improved design in construction and increased efficiency in operation, in the most refined types of modern locomotives, consists of two single-expansion engines, one on each side of the locomotive, connected to crank pins, located at right angles to each other, fitted in driving wheels on the same shaft or axle. On this class of locomotive the steam which is generated in the boiler enters the throttle valve, passes through the dry pipe to the steam chest on each side; from there it is admitted by the valves, operated by a simple link gear, to alternate ends of the cylinders, forcing the pistons backward and forward, and after performing work exhausts to the atmosphere by way of the exhaust pipe.

The compound locomotive has two or more cylinders so arranged that steam having performed work in the first cylinder or cylinders passes to the second cylinder or cylinders and performs additional work before exhausting to the atmosphere. The cylinder or cylinders that steam is admitted into first are termed *high pressure,* and those into which it is admitted last are termed *low pressure.*

The prevailing types of locomotive valve gears used in this country, even on the most modern types, employ some form of link, as applied in the Stephenson or the Walschaerts gears, or its equivalent in the Baker gear, for operating the valves that control steam distribution in the cylinders, which is so designed that reversal of motion and variable cut-off in steam admission can be accomplished by means of simple control apparatus manipulated by the engineer. Such gears enable the

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locomotive to exert its greatest tractive force, when required, by admitting steam at boiler pressure against the piston for practically its full stroke; or, when less than full tractive force is required or operating at high rates of speed and the demand for steam from the boiler is commensurate with its steaming capacity, permits working steam expansively in the cylinder, utilizing the steam's heat energy most efficiently.

Locomotive boilers are peculiar in having furnace and boiler contained in one shell. The furnace or firebox, which very much resembles a box, sets in the back part of the boiler, with an intervening water space of about five inches between it and the outside shell, the two being securely fastened together, as will be more fully explained in the part on boilers. Tubes of about two inches diameter, extending between the firebox and the smoke box at the front end of the boiler, serve to conduct the products of combustion from the fire.

The frames, virtually the foundation of the locomotive, driving wheels, trucks and their minor parts form a carriage that carries the boiler and cylinders. Practically the entire weight of the locomotive is distributed through a system of equalizing levers and springs to the driving wheels and the trucks. This part of the locomotive, termed the running gear, if properly designed, works harmoniously together and produces smooth running and good riding properties.

PROCESSES INVOLVED IN LOCOMOTIVE OPERATING.

To overcome the resistance of a train a steam locomotive uses the potential energy of coal or other fuel in producing the required impelling or tractive force, and in such transformation of energy four distinct processes are involved:

1. COMBUSTION OF FUEL.
2. GENERATION OF STEAM.
3. UTILIZATION OF STEAM.
4. IMPULSION BY ADHESION OF THE DRIVING WHEELS.

1. *Combustion of Fuel.*—Coal and petroleum oil are the principal locomotive fuels, which are burned in the firebox of the boiler. To obtain the greatest efficiency from coal, it must be burned at the proper rate, depending on the kind and grade of coal. If the rate of combustion be too low, there are likely to be losses from excess air and incomplete combustion owing to comparatively low firebox temperature; while if the rate be too great, the necessarily severe draft will carry off unburned a considerable quantity of the smaller particles of coal. The most desirable rate is about 100 pounds of bituminous coal per square foot of grate per hour, though locomotives frequently consume coal at a rate of from 150 to 200 pounds per hour, aggre-

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gating from 6000 to 8000 pounds in the same time in locomotives having from 40 to 60 square feet of grate area. The coal consumption increases rapidly as speed is increased, owing, in a great measure, to the greater, and also less efficient, rate of combustion produced by the severe draft of the exhausting steam.

The limiting factor in the developing of power in the modern locomotive is the physical endurance of the fireman, for it has been found by experience that an average fireman cannot put in the firebox more than from five to six thousand pounds of coal per hour as a regular performance, though some strong firemen can exceed this rate for short periods of time. Tests have demonstrated that a locomotive at high speed will develop a horse power hour on a consumption of from five to six pounds of coal, and that this can be obtained from a heating surface of two to three square feet. At such a rate of coal consumption, the horse power capability of the average fireman is not much greater than 1300 horse power, though locomotives are being built having from 5000 to 6000 square feet of heating surface, which should be capable of developing from 2000 to 2500 horse power.

This limiting of the steaming capacity of the locomotive boiler, owing to the physical inability of the fireman to handle sufficient coal to maintain steam pressure, brought about considerable experimenting and has resulted in the introduction of mechanical devices for assisting the fireman, the latest development in this line being the stoker, of which there are several designs that now give promise of success and extensive use. With some types of stokers the coal is spread over the top of the fire, while with others the coal is underfed—that is, introduced underneath the bed of burning fuel. In one of the underfeed types, the coal is pushed forward in troughs by means of plungers and becomes distributed over the grate. In another underfeed type the same operation is performed by worms similar to those used in flour mills. With both of these underfeed types the coal is conducted from the tender to the stoker by a conveyor.

The performance of stokers has already shown some economy in fuel consumption and a considerable reduction in smoke emission by their use, though the principal point in their favor is that they enable greater horse power to be obtained from the large locomotive than is possible with hand firing.

The advent of the large locomotive, with its great draught on the boiler for steam, necessitating the combustion of great quantities of fuel, has also led to the extensive use of oil for fuel, especially in the southwestern part of the United States, where the Texas and California oil fields produce a fuel that not only eliminates the steaming capacity limitation factor owing to the limit of physical endurance of the firemen, but enables steam to be generated at a cost considerably less than that for coal in the same territory. Tests have demonstrated

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that four barrels of oil are practically equivalent in heating value to a ton of coal, and as it requires about six barrels of oil to weigh a ton, the ratio of heating value of oil to coal is as 3 is to 2.

The usual method of feeding oil to a locomotive firebox is by means of a special injector or atomizer, generally called a burner, from which the oil is forced by steam pressure in a spray and burns in this form. In order to maintain a uniform high temperature in the firebox, the firebox is partly lined with fire brick, which becomes hot enough to ignite the oil and assists in the process of combustion. Formerly the burner was placed in the back end of the firebox, spraying the oil ahead underneath a brick arch, but the latest practice is to place it in the forward part of the firebox and spray the oil back on a flash wall.

2. *Generation of Steam.*—Part of the heat produced by combustion in a locomotive firebox is transferred, by radiation from the fire and by convection of the hot products of combustion, to the heating surface, and being absorbed by the water steam is generated.

The power of a locomotive is limited by its boiler's *steaming capacity*—that is, the boiler's ability to supply volume of steam as well as pressure, for steam is quantitive and to perform useful work it is necessary for it to have not only pressure but also volume. Owing to space and weight restrictions locomotive boilers must be enormously rapid steam generators in order to supply the requisite amount of steam to the cylinders. This necessitates a large area of heating surface compared with the volume of water carried in the boiler; and, owing to the small space available for the grate, a high rate of combustion must be maintained, which is rendered possible by action of the draft induced by the exhausting steam. The water in the boiler is enabled to absorb the bulk of the great quantity of heat generated in the firebox owing to effective circulation, which is promoted by the vibration of the moving locomotive, maintaining the efficiency of the locomotive boiler on a par with the best land and marine boilers in spite of unfavorable conditions for economical fuel consumption.

It is not definitely known as to the actual rate at which heat transfer takes place at different parts of the heating surface, but it seems certain that evaporation progresses much more rapidly from the firebox heating surface and the tube heating surface near the firebox than heating surface remote from the firebox, where the products of combustion are at a much lower temperature than in the firebox. Possibly the rate of evaporation from the hottest parts of the heating surface is at least ten times the average rate for the whole heating surface, but there is not sufficient experimental data on record to establish exact figures for this relation.

The amount of water required by locomotives is generally stated as being between the limits of 20 to 30 pounds per indicated horse power hour. This water converted into steam is not all utilized by the cylin-

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ders. Considerable steam is used by the air pump, steam heat apparatus, injectors, etc., and some is wasted at the safety valves and also by leakage.

The evaporative power of a boiler is usually expressed in units of equivalent evaporation—*i.e.*, in pounds of water evaporated from and at 212° F. at atmospheric pressure. In the locomotive type of boiler it is possible for the water to absorb sufficient heat to evaporate from twelve to fifteen pounds of water, from and at 212° F., per hour for each square foot of heating surface, though eight to ten pounds is nearer average conditions.

The power developed by the locomotive boiler, measured by the quantity of steam produced, is limited chiefly by the size of grate, the relative heating surface, and the maximum rate of fuel consumption. The proportionate relation of these three features is the most important one taken into account in the designing of efficient boilers.

It is usual to design bituminous coal burning locomotive boilers with a total heating surface area equal to sixty to sixty-five times the grate area. This ratio has been found to provide enough heating surface to efficiently absorb the heat generated on the grate by combustion. If the heating surface is much less than sixty times the grate area, more heat will be generated than can be transferred to the water, and the boiler will lose efficiency owing to the escape of the products of combustion before the walls have absorbed their heat. On the other hand, if the heating surface is much greater than sixty-five times the grate area, the increase in heat absorbing capacity and resulting efficiency is so slight that they will not compensate for the increased weight and expense involved. For the burning of anthracite and lignite coals the ratio of heating surface to grate area is less than boilers designed for bituminous coal burning, owing to the larger grate areas employed for their combustion. Large grate areas are necessary for the efficient burning of these coals owing to anthracite burning slowly, and because the low heating value of lignite coal necessitates a greater quantity being burned than when bituminous is used in order to generate in the aggregate the same quantity of heat.

Throughout the country about twenty-five years ago the prevailing allowed locomotive boiler pressure was about 125 pounds per square inch. During the intervening time, which has been the period of greatest development in locomotive construction, the allowed pressures have been increased, and now the usual steam pressure of locomotive boilers generating saturated steam is about 200 pounds, though on some few locomotives pressures as high as 225 to 240 pounds are carried. This increase of pressure was accompanied by more rapid deterioration of boilers and greater cost in their maintenance, both of which increased in a greater ratio than the increase in pressure. With the introduction of superheaters there has been a tendency to reduce

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boiler pressure from about 200 pounds to pressures between 160 and 180 pounds, increasing the cylinder volume so as to maintain a tractive effort equivalent to that obtained with the higher boiler pressure. The object of lowering boiler pressure is in line with the effort to increase boiler efficiency and reduce the cost of boiler repairs, which has become excessive.

3. *Utilization of Steam.*—As the steam is used in the cylinders, part of its heat energy is transformed into mechanical work, which appears in the rotating of the driving wheels.

Considered from a steam engineering basis, locomotive cylinders are very large compared with their boiler's steaming capacity, usually being designed of such size that, by using steam at boiler pressure for practically full stroke, the adhesive force between driving wheels and rails can be fully utilized when utmost tractive effort is required, as when starting heavy trains and ascending grades. But maximum tractive effort can be maintained only at fairly slow speeds, for a boiler's steaming capacity depends almost entirely on the areas of the grate and heating surface, unchanging factors, and the rate of fuel consumption, while the rate at which the cylinders use the steam is affected both by the point of cut-off and the speed of the locomotive.

To make use of steam most efficiently in locomotive cylinders—that is, to utilize the greatest possible percentage of heat energy in the steam, it is necessary to use steam of high pressure, and to use it expansively.

But expansion of saturated steam in a cylinder is accompanied with *condensation* and consequent heat losses (see Cylinder Condensation and Re-evaporation in Cylinder, Steam, Part IV), becoming excessive at high ratios of expansion, especially when taking place in locomotive cylinders, which are crudely protected and very much exposed to the cooling effects of outside temperatures.

Various means and devices have been introduced for obviating cylinder condensation losses, but *superheaters,* superheating steam to temperatures of from 500° F. to 650° F., one of the recent improvements applied to locomotive construction that seems to be gaining favor rapidly, and the use of compound cylinders are practically the only measures employed for this purpose on locomotives. The use of superheated steam, while accompanied with some minor mechanical and lubricating troubles that no doubt will be overcome in course of time, has given such high efficiency in so many respects, effecting considerable economy in fuel and water consumption, owing to the increased volume of steam per pound of water evaporated, and its characteristic properties—greater specific volume and more complete gasification—produce a more powerful and smarter locomotive, even when working at a boiler pressure lower than ordinarily allowed on locomotives using saturated steam, that its general use seems certain,

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to the exclusion of all other means of obviating condensation in locomotive cylinders. (See Use of Superheated Steam, Part 4.) Compound cylinders are applied for the further purpose of avoiding mechanical difficulties attendant to a high ratio of expansion of high pressure steam in a single cylinder.

The advantages obtained by compounding compared with single cylinders are: First, ability to secure a greater degree of expansion of steam with a reduction of cylinder-condensation, clearance space and leakage, effecting economy in steam consumption; for with compound cylinders the temperature of steam exhausted from the high pressure cylinder is higher and its range of temperature change between admission and release is lower than when all the expansion is provided for in one cylinder, and the range of temperature change in the low pressure cylinder is proportionately low, and this low range of temperature change of metal surfaces in each cylinder of compound engines results in a diminished loss by cylinder-condensation, and, further, the steam lost in the high pressure cylinder owing to leakage and clearance spaces does work in the low pressure cylinder. Second, on some types, particularly balanced and also Mallet types, the pressure on crank pins and frames is divided so as to avoid excessive friction and shocks.

To most efficiently utilize steam in the cylinders of a locomotive, the proper regulating of pressure and quantity of steam to its requirements at various loads and speeds is most important, affecting not only the efficiency of the machine but also the fuel and water consumption to a greater extent than any other feature; for, owing to the physical characteristics of railroads, loading conditions, etc., locomotives work under continually changing conditions, the loads they are required to pull and the speeds at which they run varying between the extremes of light or slow and the heaviest or fastest the machine is capable of developing. When operating at loads requiring less than full tractive effort, the effective pressure on the piston must be reduced, and at higher speeds the quantity of steam per stroke—not necessarily per unit of time—must be curtailed; for in the first case, if effective pressure were not reduced excessive speed would result, while in the second, quantity must be curtailed or the cylinders will use steam faster than the boiler can generate it, resulting in a steam failure. Of course, both pressure and quantity can be regulated in a manner by the throttle valve, though even this method would be impracticable at high speeds. The practicable and also the economical way is to admit steam to the cylinder at boiler pressure, cut off the supply at a point in the piston's stroke that will give a mean effective pressure sufficient to meet the requirements of the particular load and speed.

4. *Impulsion by Adhesion of the Driving Wheels.*—The driving wheels are rotated by suitable mechanical connections between the

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pistons working in the cylinders and the crank pins, and the locomotive is impelled forward, because of the friction between the wheels and the rails. This friction between the driving wheels of a locomotive and the rail is termed *adhesion*. The effectiveness of adhesion depends greatly on the weight with which each driving wheel surface rests on the rail; the surface condition of the rails, and to some extent on the physical properties of the steel in the wheel tires and the rails. The proportion of adhesion to the weight of driving wheels on the rail is about as follows:

(*a*) On dry-sanded rails it is equal to one-third.

(*b*) On perfectly dry, clean rails it is one-fourth.

(*c*) Under ordinary conditions, without sand, or sanded wet rails, one-fifth.

(*d*) On wet or frosty rails, one-sixth. With snow or ice on the rails the adhesion becomes still less.

The proportion of adhesion to weight on the driving wheels means in case (*a*) that if a locomotive had a weight of 200,000 pounds on the driving wheels, the resulting friction between wheels and rail would permit of an impelling force at the points of contact of one-third this amount, or about 66,666 pounds; in case (*b*) one-fourth, 50,000, and so on.

The *tractive effort* of a locomotive, as will be shown later, depends on size of cylinders, mean effective steam pressure on pistons, and diameter of driving wheels; but hauling capacity is practically governed by adhesion of drivers to the rail, for if there is not enough adhesive weight the drivers will slip. Thus it is apparent that adhesion sets a limit on the tractive effort of a locomotive of given weight on drivers, irrespective of its cylinder power; for if the cylinder power be greater than this limiting point the driving wheels slip, the tractive effort is not increased, but actually diminishes as the wheels slip; or, the adhesion of the driving wheels is very much less when they slip than when they roll without slipping.

With locomotives of good design the ratio of adhesion to tractive effort lies between the limits of 4 to 1 and 5 to 1, which means that, for each pound of calculated tractive effort there is from four to five pounds weight placed on the drivers. To meet fairly good everyday conditions it has become the established practice in locomotive designing to assume that the weight on driving wheels limits the tractive effort of passenger locomotives to 23.5 per cent.; of freight locomotives to 22.2 per cent., and of switching locomotives to 20 per cent. of the adhesive weight. That is, the weight on driving wheels of passenger locomotives should be at least four and one-quarter; of freight locomotives four and one-half; and of switching locomotives five times as much as the maximum tractive effort of locomotives in these respective classes of service.

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POWER OF LOCOMOTIVES.

The power of locomotives is expressed in two ways: *Tractive Effort* or *Tractive Power,* and *Horse Power.*

The tractive effort rating, the phrase most generally used in connection with the power of locomotives, determined from a calculation involving volume of cylinder, mean effective pressure, and diameter of drivers, means hauling capacity in pounds pull on the draw-bar, irrespective of speed, assuming that there is sufficient weight on the drivers to furnish necessary adhesion. Of course, the actual pull on the draw-bar is less than the calculated tractive effort, for the friction of machinery and journal bearings of the locomotive and tender absorbs considerable power. *Tractive effort* would seem to be a better phrase than *tractive power,* as a locomotive might exert its utmost effort to pull a train and yet develop very little power; for instance, a stalled locomotive with wide open throttle and full boiler pressure in the cylinders, exerts its utmost effort to pull the train, but develops no power.

The horse power is both *indicated* and *dynamometer.* Indicated horse power is the horse power developed in the cylinders; while dynamometer horse power is the horse power delivered at the draw-bar, and equals indicated horse power less the power absorbed by friction of machinery and journal bearings.

Horse power is proportional to the product of tractive effort and speed and so the weight of train that can be hauled at any particular speed depends upon the tractive effort that the locomotive can develop at that speed. Therefore, the speed at which a train of given weight can be hauled by a locomotive depends upon its horse power, which in turn depends upon the steaming capacity of the boiler.

At fairly slow speeds, steam admitted full stroke, it usually is assumed that the mean effective pressure equals eighty-five [1] per cent. of the boiler pressure; but on increasing speed, a speed is soon reached at which it is impossible to maintain this pressure, owing to the limited size of locomotive boilers, hence cut-off must take place earlier and consequent reduction in available tractive effort ensues. The maximum cut-off point of any locomotive running at a given high speed depends on the relation between its calculated tractive effort and its total heating surface, that is, the ratio between these two

[1] Eighty-five per cent. of boiler pressure has been fixed by the American Master Mechanics' Association as the steam pressure factor in making tractive effort calculations. This figure proved fairly reliable for the older types of locomotives, but recent tests have indicated that it is too low for the latest types, that have improved or more efficiently designed valve gears, large valves, more direct steam or exhaust ports, piping and passage ways, all of which tend to improve steam distribution so as to obtain a greater mean effective pressure.

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features, which varies on different locomotives, and the lower this ratio the longer the cut-off permissible.

The curves in the diagram Fig. 1 show the per cent. drop in available tractive effort that occurs as speed is increased, which is the result of a proportional decrease in mean effective pressure, and that the available tractive effort depends on the ratio between the calculated tractive effort and the total heating surface. As this ratio differs on different locomotives, several curves are shown, ending at the small figures 6, 8, 10, 12, 14, 16, which are the ratios obtained by dividing the calculated tractive effort by the total heating

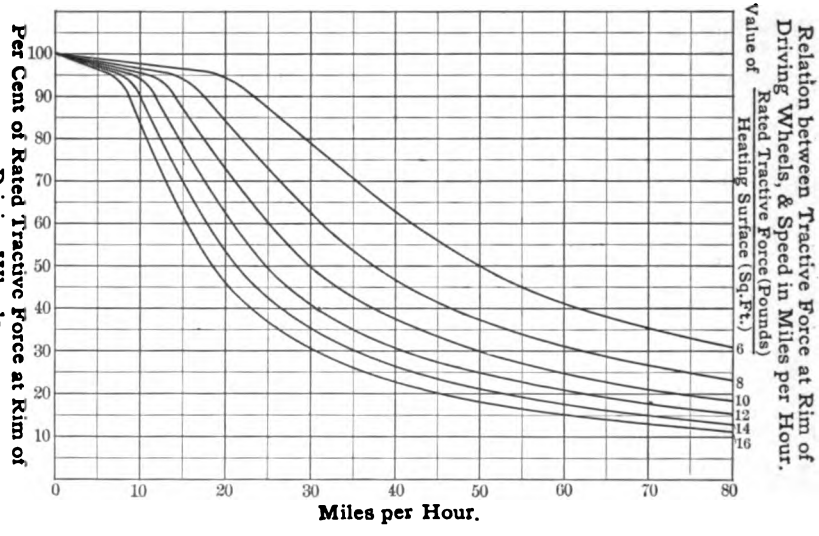

FIG. 1.—Curves showing tractive effort drop as speed is increased.

surface. For example, selecting a locomotive having a calculated tractive effort of 30,898 pounds and a total heating surface of 4771 sq. ft., $\frac{30,898}{4771} = 6.4$, and so the curve ending at 6 should be used for this particular locomotive. Reference to the curve shows that at a speed of 60 miles per hour this locomotive should develop about 40 per cent. of its calculated tractive effort, and from this it can be calculated that the mean effective pressure in the cylinders would equal about 34 per cent. of the boiler pressure.

From the preceding matter on the power of locomotives, it may be noted that tractive effort depends on the mean effective pressure alone, while horse power depends on both mean effective pressure and the speed; that as the speed increases the indicated horse power increases also, and so at highest speed the horse power is a maximum,

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though the tractive effort developed is only a fraction of that obtained at slow speed, and that tractive effort is draw-bar pull, but does not necessarily imply actual motion of the locomotive, while horse power is rate of doing work—the draw-bar pull producing motion and resulting in definite results.

TRACTIVE EFFORT AND HORSE POWER FORMULÆ.

The calculating of Tractive Effort and Horse Power of locomotives is not a complicated matter, and the few algebraic formulæ used in this subject merely express in a simple, graphic way the order of procedure, using symbols for which real values must be substituted in actual calculations. Each formula, applicable to relating class of locomotive in Representative Types, Part 2, is followed by a practical example, showing the operation in detail.

The phrases, symbols and constants used in these formulæ are as follows:

T. E. = Tractive Effort.

H. P. = Horse Power.

P. = Rated boiler pressure in pounds per square inch above atmospheric.

p = Mean effective pressure. At slow speed, cut-off 100 per cent., in tractive effort calculations, mean effective pressure is usually assumed to be equal to 85 per cent. of rated boiler pressure P.

d_H = Diameter of high pressure cylinders, inches (or diameter of cylinders of simple locomotives).

d_L = Diameter of low pressure cylinders, inches.

A = Area of piston, square inches.

S = Length of stroke, inches.

L = Length of stroke, feet.

N = Number of strokes of piston per minute.

D = Diameter of driving wheels, inches.

M.P.H. = Miles per hour.

3.1416 = Ratio of circumference to diameter of circle. It is the constant used for multiplying the diameter of circle, the resulting product being the circumference.

.7854 = a constant used for multiplying the squared diameter of a circle, the resulting product being the area of the circle.

The figure "2" placed at the upper right of a symbol or number, thus 24^2, d_H^2, means that the number, or the number represented by the symbol, must be squared, *i.e.*, the number must be multiplied by itself. For example, 24^2 means $24 \times 24 = 576$.

The tractive effort of any locomotive, of known characteristics, can be ascertained by the following process:

Multiply together separately the areas (A) of each piston, the

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mean effective pressure (p), the length of stroke (S) and 2 (2, because there are two strokes per revolution of driving wheels); divide the resulting product by the diameter (D) of driving wheels; add the several quotients together, and the result is the total tractive effort of the locomotive.

For example, selecting a two cylinder simple locomotive of the following characteristics:

d_H (diameter of cylinder) = 23.5 inches.
S (stroke of piston) = 26 inches.
D (diameter of drivers) = 79 inches.
P (rated boiler pressure) = 200 pounds.
From which we get,
p (mean effective pressure) = 85 per cent. × P = .85 × 200 = 170 pounds per sq. in.
A (area of piston) = $d_H^2 \times .7854 = 23.5 \times 23.5 \times .7854 = 433.74$ sq. ins.
Circumference of driving wheels = D × 3.1416 = 79 × 3.1416 = 248.19 inches.
Then the tractive effort for one cylinder equals,

$$\frac{A \times p \times S \times 2}{D \times 3.1416} = \frac{433.74 \times 170 \times 26 \times 2}{79 \times 3.1416} = 15449 \text{ lbs.}$$

This becomes somewhat clearer on considering the relation between the energy expended by the steam in the cylinder and that appearing as mechanical work at the periphery of the driving wheels. During the two strokes of the piston (one revolution of the driving wheels) the work performed by the steam in the cylinder equals,

$$\frac{433.74 \times 170 \times 26 \times 2}{12} = 319521.8 \text{ foot pounds.}$$

At the same time the locomotive moves forward $\frac{248.19}{12} = 20.682$ feet; therefore the 319,521.8 foot pounds of energy developed in the cylinder is exerted through a space of 20.682 feet; and so the force delivered at the point of contact between driving wheel and rail, tending to impel the locomotive forward, equals,

$$\frac{319521.8}{20.682} = 15449 \text{ lbs.}$$

Of course, the total tractive effort of the locomotive would be obtained in this example by multiplying the tractive effort of the one cylinder, 15,449 pounds, by 2, producing 30,898 pounds. But if the power developed in each cylinder differs in amount then the two (or more) amounts must be added together to obtain the total tractive effort.

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This entire process can be presented in one formula, thus,

$$\text{T.E.} = \frac{d_H^2 \times .7854 \times S \times .85 \times P \times 2 \times 2}{D \times 3.1416} = \text{by cancellation,}$$

$$\frac{d_H^2 \times S \times .85 \times P}{D} = \text{, substituting for example given,}$$

$$\frac{23.5 \times 23.5 \times 26 \times .85 \times 200}{79} = 30898 \text{ pounds.}$$

The formula, $\frac{d_H^2 \times S \times .85 \times P}{D}$, is the one generally employed for calculating the tractive effort of simple or single-expansion locomotives.

The tractive effort of balanced compound locomotives, working simple, may be ascertained by the following formula:

$$\text{T.E.} = \frac{S \times P}{D} \times (2/3 \times d_H^2 + 1/4 \times d_L^2).^a$$

For example, selecting a four cylinder balanced compound of the following characteristics:

$d_H = 17.5$ inches.
$d_L = 29$ inches.
$S = 28$ inches.
$P = 210$ pounds.
$D = 73$ inches.

Then

$$\text{T.E.} = \frac{28 \times 210}{73} \times (2/3 \times 17.5 \times 17.5 + 1/4 \times 29 \times 29) = 33380 \text{ pounds.}$$

The tractive effort of Baldwin Mallet articulated compound locomotives can be ascertained by the following formula:

$$\text{T.E.} = \frac{d_H^2 \times S \times 1.2 \times P}{D}.^a$$

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[a] These two formulæ are promulgated by the Baldwin Works for calculating the tractive effort of the balanced and articulated compound types built by them. The factors ⅔, ¼ and 1.2 used in the formulæ are not mathematical constants, but are simply abstract numbers, deduced from data obtained by tests of those respective types, that produce the theoretical tractive effort as near as practicable to calculate it.

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For example, selecting an articulated compound of the following characteristics:

$d_H = 25$ inches.
$S = 28$ inches.
$P = 200$ pounds.
$D = 63$ inches.

Then

$$\text{T.E.} = \frac{25 \times 25 \times 28 \times 1.2 \times 200}{63} = 66666 \text{ pounds.}$$

The term horse power is not generally used in connection with the operating of locomotives, though there are times when it is interesting to make comparisons in this unit. A horse power is equal to the force of 33,000 pounds exerted through a space of one foot in one minute. This statement, in connection with the steam engine, can be expressed by the following formula:

$$\text{H.P.} = \frac{p \times L \times A \times N}{33000}.$$

For example, selecting a two cylinder simple locomotive of the following characteristics running at a speed of 60 miles per hour,

d_H (diameter of cylinders) $= 23.5$ inches.
S (stroke of piston) $= 26$ inches.
L (stroke of piston) $= 2\frac{1}{6}$ feet.
D (diameter of drivers) $= 79$ inches.
P (rated boiler pressure) $= 200$ pounds.
p (mean effective pressure) $= 34$ per cent. $\times$ P $= .34 \times 200 =$ 68 pounds per sq. in.
A (area of piston) $= d_H^2 \times .7854 = 23.5 \times 23.5 \times .7854 = 433.74$ sq. ins.
N (number of strokes per minute) $= 1021$.[3]

Then the horse power of the locomotive equals,

$$\frac{68 \times 2\frac{1}{6} \times 433.74 \times 1021}{33000} = 1977 \text{ H. P.}$$

[3] The number of strokes per minute, is obtained by dividing the circumference of the driving wheel in feet into the number of feet passed over by the locomotive in one minute, which in this case is 5280 or one mile, and multiplying this by 2, as there are 2 strokes per revolution, and again by 2, as there are two cylinders.

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Another formula for calculating the horse power of locomotives is as follows:[4]

$$\text{H.P.} = \frac{d_H^2 \times S \times p \times (\text{M. P. H.})}{D \times 375}$$

For example, selecting the same locomotive and same conditions as used in previous example:

$$\frac{23.5 \times 23.5 \times 26 \times 68 \times 60}{79 \times 375} = 1977 \text{ H.P.}$$

TRAIN RESISTANCE.

Recent tests have shown that train resistance varies not only with the speed, but also with the weights of the cars of which the train is composed. At a given speed the tractive effort required for each ton of weight of the train will be greater, for example, for a train that is composed of cars of 20 tons gross weight than for a train composed of cars that weigh 75 tons each. Thus, a car weighing 75 tons is seen, from the curve on the diagram, Fig. 3, to have a resistance of 5 pounds per ton at a speed of 35 miles per hour, while a car weighing only 20 tons has a resistance of 11.1 pounds per ton at the same speed.

The curves in the diagrams Figs. 2, 3, 4, show the resistance in pounds per ton of locomotives, freight cars and passenger cars. The resistances shown by these curves are locomotive and train resistances when moving on level, straight track, and are the result of friction of the running gear of the locomotives and cars. Track curvature increases the resistance of trains.

When trains are hauled up grades the resistance owing to the lifting of the weight of the train against gravity must be added to the frictional resistance. The grade resistance is determined as follows: One mile equals 5280 feet, and if the grade be one foot per mile, the pull necessary to lift a ton of 2000 pounds will be $\frac{2000}{5280} = .3788$ pound. Therefore to find the total resistance due to grades in pounds per ton of 2000 pounds, the rise in feet per mile must be multiplied by .3788. If the grade is expressed in feet per hundred, or in per cent., the resistance in pounds per ton of 2000 pounds will be $\frac{2000}{100} = 20$ pounds for each per cent. of grade.

[4] The number 375 used in this formula is a constant.

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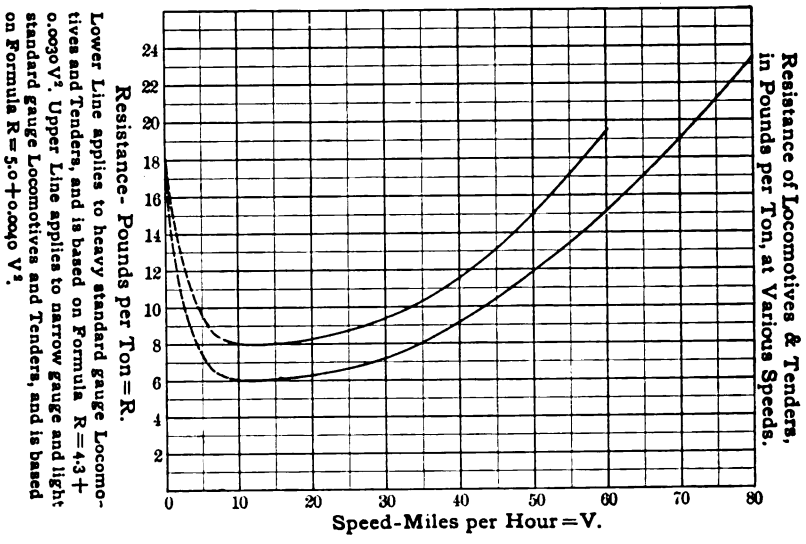

FIG. 2.—Locomotive resistance.

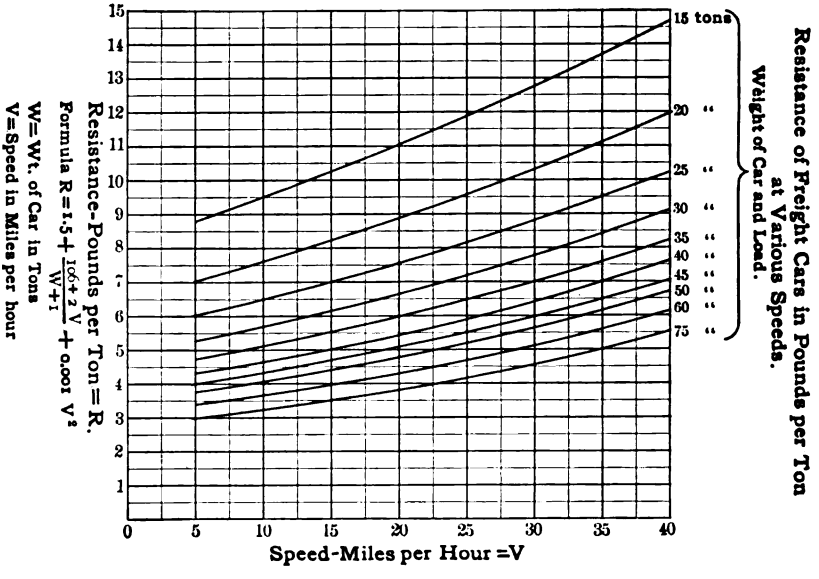

FIG. 3.—Freight car resistance.

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The resistance owing to curvature, as given by various authorities, ranges from .5 to 1.5 of a pound the ton per degree of curvature, and so one pound per ton is considered a fair average.

The following two examples illustrate the methods of calculating the hauling capacities of freight and passenger locomotives respectively.

Freight.—What weight of train composed of cars weighing 75 tons each can be hauled up a grade of .5 per cent. combined with a 6 degree

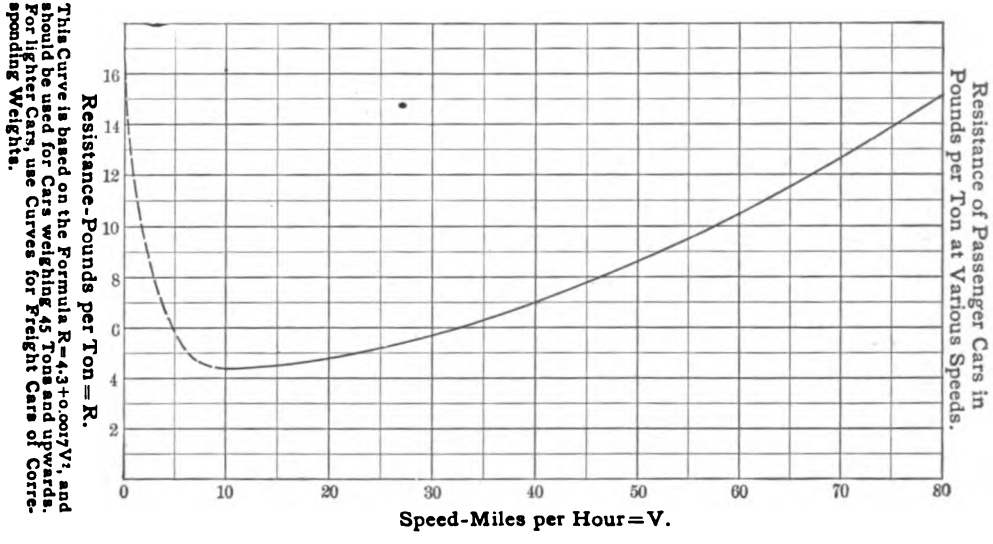

FIG. 4.—Passenger car resistance.

curve at a speed of 10 miles per hour by a locomotive of the following dimensions and characteristics?

Cylinders, 24 inches × 28 inches.
Steam pressure, 205 pounds.
Driving wheel diameter, 62 inches.
Tractive effort, 45,327 pounds.[5]
Total weight, locomotive and tender, 198 tons.

At a speed of 10 miles per hour the curves show a resistance of 6 pounds per ton for locomotive and 3.25 pounds per ton for freight cars of 75 tons weight.

[5] As the speed is slow in this case, it is assumed that a mean effective pressure equal to 85 per cent. of boiler pressure is obtained in the cylinders, and that the locomotive develops its rated calculated tractive effort.

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In order to get the available draw-bar pull for hauling the train, it is first necessary to obtain the resistance of the locomotive and tender in pounds and subtract this from its calculated tractive effort. The resistance of the locomotive and tender is calculated as follows:

Resistance, frictional,	10 M.P.H. $= 198 \times 6 =$	1188 pounds
Resistance, grade,	$198 \times .5$ per cent. $\times 20 =$	1980 pounds
Resistance, curve,	$198 \times 6 =$	1188 pounds
Total resistance, locomotive and tender		4356 pounds

The available draw-bar pull for hauling the train will be 45,327—4356 = 40,971 pounds.

The resistance in pounds per ton of trains is calculated as follows:

Resistance, frictional,	=	3.25 pounds
Resistance, grade,	$= .5$ per cent. $\times 20 =$	10.0 pounds
Resistance, curve,	$(1 \times 6) =$	6.0 pounds
Total resistance, pounds per ton	=	19.25 pounds

Hence the number of tons the locomotive can haul back of the tender will be equal to the available draw-bar pull divided by the resistance of one ton $= \frac{40971}{19.25} = 2128$ tons, which would be equivalent to about 28 cars weighing 75 tons each.

Passenger.—What weight of train can be hauled up a straight grade of .3 per cent., at a speed of 60 miles per hour by a locomotive of the following dimensions and characteristics?

Cylinders, 23½ inches × 26 inches.
Steam pressure, 200 pounds.
Driving wheel diameter, 79 inches.
Tractive effort, 12,358 pounds.[6]
Total weight, locomotive and tender, 212 tons.

At a speed of 60 miles per hour the curves show a resistance of 15 pounds per ton for locomotives and 10.5 pounds per ton for passenger cars of 45 tons weight or greater.

The resistance of locomotive and tender is as follows:

Resistance, frictional, 60 M. P. H.	$= 212 \times 15 =$	3180 pounds
Resistance, grade,	$212 \times .3$ per cent. $\times 20 =$	1272 pounds
Total resistance, locomotive and tender	=	4452 pounds

[6] At a speed of 60 M.P.H. the tractive effort of the locomotive falls to 12,358 pounds, as the mean effective pressure in the cylinders would be but 34 per cent. of boiler pressure.

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The available draw-bar pull for hauling the train will then be $12{,}358 - 4452 = 7906$ pounds.

The resistance in pounds per ton of the train is as follows:

Resistance, frictional,	= 10.5 pounds
Resistance, grade, .3 per cent. $\times$ 20 =	6. pounds
Total resistance, pounds per ton	= 16.5 pounds

Hence the number of tons the locomotive can haul back of the tender in this case $= \frac{7906}{16.5} = 479$.

EFFICIENCY OF LOCOMOTIVES.

To acquire the proper idea of a machine's efficiency in its adaptation to useful purposes in any field of engineering, one must have a knowledge of the efficiencies obtainable from other machines of similar characteristics, for an analysis of efficiency values would be misleading unless made on a basis of comparison. For example, an efficiency value of 65 per cent. for steam boilers would be considered rather low, while on the other hand steam engine efficiencies even as great as 20 per cent. probably have never been attained, and so boilers must be compared with boilers, engines with engines, etc., in order to make such information of practical value.

The pure theoretical efficiency of a locomotive, considered as a machine or prime mover, is the ratio of the net draw-bar pull in foot-pounds to the foot-pounds of energy expended by the combustion of fuel in the firebox, but on the broad lines of customary usage, efficiency embraces performance issues in nearly every phase of locomotive operating. As locomotive efficiency, in the broad sense, is too comprehensive for treatment here, the matter presented will be restricted to the following divisions:

A. THEORETICAL EFFICIENCIES.
B. RELIABILITY OF SERVICE.
C. OPERATING COSTS.

A. Theoretical Efficiency.—The rate of steam and fuel consumption per horse power hour of the engines, the evaporative duty of the boiler and the percentage of cylinder power that reappears as a stress or pull on the draw-bar, and the agencies reacting on and affecting these phases of locomotive performance, will form the basis of subject matter in this division.

It is customary to compare the performance of locomotive boilers and engines with that of stationary boilers and engines, the locomotive's rank as a steam power plant being based on efficiencies so ob-

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tained. Tests for efficiency on this basis are conducted in two ways: Road tests in actual service, and by means of locomotive testing plants.

A locomotive testing plant consists of a system of supporting wheels revolving on fixed axles upon which are mounted the driving wheels of the locomotive under test. The draw-bar is attached to a stationary dynamometer where the locomotive's pulling effects are indicated. During tests it is usual to run the locomotive at a predetermined, constant speed, with a given cut-off and throttle opening, the power delivered at the periphery of the driving wheels being regulated to suit the cylinder power by applying brakes to the supporting wheel mechanism. Thus the complete operation of the locomotive is provided for in just the same manner as when in service on the road, while its relatively fixed position permits study of performance characteristics with the same facility as that of a stationary steam power plant of the most refined sort.

The rate of steam consumption per horse power hour of locomotives is affected by the mode of utilizing the steam in the cylinders, single expansion or compound; the physical properties of the steam, saturated or superheated; the type of valve gear and valve used for controlling steam distribution; and the operating conditions, load, speed, cut-off, etc.

The following table shows the average rate of steam consumption obtained in recent tests on testing plants of both simple and compound locomotives:

STEAM PER INDICATED HORSE POWER HOUR.

	Simple Locomotives		Compound Locomotives	
	Passenger	Freight	Passenger	Freight
Minimum consumption, lbs.....	23.81	23.67	18.86	20.26
At maximum load, consumption, lbs.	23.81	23.83	21.39	22.03
Maximum consumption, lbs.....	33.54	28.95	24.41	25.31

In these tests, the performance of compound freight locomotives compared with that of simple freight locomotives was very favorable to the compounds; but the mode of conducting tests, *i.e.*, the continuous operating of the locomotive at constant speed and load, presents the most favorable conditions for efficiently operating compound locomotives. These tests also demonstrated that the steam consumption of compound locomotives increases with increase of speed, while that of simple locomotive decreases.

Table S, which has been compiled from data obtained in several

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tests of the same locomotive, that was fitted for generating and using saturated steam and superheated steam successively, shows the extent to which the rate of steam consumption is affected by the physical properties of the steam, and also that boiler pressure has some effect in the same connection. The figures show that with the use of saturated steam there is a decrease in steam consumption as the boiler pressure is increased, though not proportional to the pressure increases; that superheated steam is more economical than saturated steam at all boiler pressures, but the highest efficiency is obtained with superheated steam at a pressure of about 180 pounds. This table also shows the coal consumption in these tests, which will be referred to later on.

TABLE S.—STEAM AND COAL CONSUMPTION UNDER DIFFERENT PRESSURES OF SUPERHEATED AND SATURATED STEAM.

Steam	Boiler Pressure (gauge)	Superheat Degrees	Pounds of Steam Per Indicated H-P. Per Hr.	B.T.U.'s Per Indicated H-P. Per Minute	Pounds of Coal Per Indicated H-P. Per Hr.
Superheated....	240	222.2	19.5	421.4	2.63
Superheated....	220	226.5	19.0	410.7	2.57
Superheated....	200	230.9	18.9	408.3	2.55
Superheated....	180	235.1	18.7	404.0	2.51
Superheated....	160	239.4	18.9	408.0	2.55
Superheated....	140	243.8	19.5	419.8	2.63
Superheated....	120	248.6	21.0	452.3	2.82
Saturated.....	240	0	24.7	483.0	3.31
Saturated.....	220	0	25.1	491.0	3.37
Saturated.....	200	0	25.5	498.0	3.43
Saturated.....	180	0	26.0	507.0	3.50
Saturated.....	160	0	26.6	517.0	3.59
Saturated.....	140	0	27.7	537.0	3.77
Saturated.....	120	0	29.1	563.0	4.00

The reason for the greater efficiency in consumption of superheated steam is entirely owing to the extinction or reduction of the internal thermal wastes in the cylinder, consequent to the phenomenon known as *initial* or cylinder condensation; for superheated steam remains steam until all of its superheat has been absorbed—that is, so long as the temperature of the steam, during both admission and expansion, is higher than the temperature of the saturated steam of the same pressure during these phases, condensation will not take place.

The rate of fuel consumption is affected by the same characteristics that affect the rate of steam consumption, and also by the rate of combustion per unit of grate area. The rate of combustion is, of course,

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greatly affected by the speed. The rate of fuel consumption per dynamometer horse power hour—that is, horse power hour delivered at the draw-bar, recorded during the tests referred to in the preceding table of steam consumption, for simple and compound passenger and freight locomotives was about as follows:

POUNDS OF COAL PER DYNAMOMETER HORSE POWER HOUR.

Speeds	Passenger		Freight	
	Simple	Compound	Simple	Compound
Slow	4.42	2.2	3.5 to 4.5	2.0 to 3.7
High	6.76	.5	5	3.2 to 3.6

In the producing of steam there are various heat losses. These losses plus the heat utilized equals the total heat of the fuel burned, and so the efficiency of a boiler is based on the ratio of the heat utilized in the producing of steam to the total contained heat of the fuel. In the locomotive boiler the heat losses may be divided into three main groups:

1. Loss of heat by imperfect combustion.
2. Loss of heat by external radiation.
3. Loss of heat in the products of combustion.

(1) Loss of Heat by Imperfect Combustion: This loss occurs in two ways: First, by the production of *carbon monoxide* (CO); second, by the escape of unburned fuel from the stack and at the grates.

The average value of the first loss, the production of carbon monoxide (CO), is probably less than 2 per cent. In the tests previously referred to the CO losses ranged from a trace at moderate rates of combustion to 16.33 per cent. in one test in which the rate of combustion was about 82 pounds of coal per square foot of grate per hour. The great loss in this one test was probably owing more to insufficient air supply than to the rate of combustion, as the rate in this instance was not excessive for locomotives.

The loss of unburned fuel, the second loss, is the most important heat loss of the locomotive boiler. Unburned fuel escapes in three ways: First, as sparks emitted from the stack; second, by dropping through the openings of the grates; third, as unconsumed gases (not including CO). The losses from this source range between 4 per cent. and 40 per cent.

(2) Loss of Heat by External Radiation: This loss has not been

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accurately determined by test under all conditions, but there is reason to assume that it reaches 5 per cent. of the heat utilized by the boiler in evaporation. Prof. Goss, of Purdue University, says that experiment has shown that a locomotive running 28 miles per hour loses by external radiation about 2 per cent. of the power developed.

(3) Loss of Heat in the Products of Combustion: The products of combustion consist of certain dry gases, as shown by an analysis of fuel gases, and in addition considerable water vapor from the water of combustion of the hydrogen in the coal, from moisture in the coal and in the air.

The amount of heat carried off by the products of combustion depends on the weights of dry gases and water vapor produced per pound of coal burned; on the temperature at which they escape to the smokebox, and on the specific heat of these substances.

At similar rates of evaporation and combustion locomotive boilers compare favorably with stationary boilers. But stationary boilers operate under practically constant conditions and are proportioned so as to obtain maximum efficiency at normal power out-put; while locomotive boilers, which are designed as large as construction limits permit, frequently have to supply inordinate quantities of steam, and so their average efficiency is lower than that of stationary boilers. The properties peculiar to the locomotive, considered as a power plant in a comparative way, give it this advantage, its boiler is capable of developing large overload horse power, even though at a considerable sacrifice of economy.

It is considered that locomotive boilers are operating at about maximum efficiency when evaporating from 10 to 12 pounds of water per pound of dry coal. Such efficiency can be obtained only when the power delivered is comparatively little, at low rates of evaporation per unit of heating surface. As the rate of evaporation increases, the efficiency rapidly lessens, becoming least when the power delivered is greatest. At an evaporation of from 12 to 15 pounds of water per square foot of heating surface per hour, which is about the limits of maximum rates, one pound of dry coal will evaporate but from 6 to 8 pounds of water. Efficiency values ranging from 40 to 80 per cent. are obtained from locomotive boilers, depending on operating conditions.

The percentage of power developed in the cylinders that reappears as stress or pull on the draw-bar, diminishes as the speed is increased. In the tests previously referred to, the per cent. of cylinder indicated horse power that reappeared as dynamometer horse power or stress on the draw-bar was as follows: At 40 revolutions per minute, the maximum was 94 and the minimum 77 per cent., and at 280 revolutions, the maximum was 87 and the minimum was 62 per cent.

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While the steam locomotive is capable of delivering a horse power at the draw-bar upon a fuel consumption of but a trifle more than 2 pounds of coal per hour, giving it high rank as a steam power plant, yet it is a fact that its average efficiency as a machine for utilizing the heat energy of fuel is decidedly less than 5 per cent.

B. Reliability of Service.—The ability of a locomotive to make the prescribed trip or day's run without a failure or disorder of itself or appurtenances, that results in delay to its own train or other traffic, establishes the basis of efficiency for making reliability comparisons in locomotive performance.

The phrase *engine failure* has various applications on different railroads throughout the country. On some railroads every deficiency in any way chargeable to the locomotive that delays a train two minutes or more is reported as an engine failure, whether or not such lost time may subsequently be made up; while other railroads consider only breakdowns of machinery or appurtenances as constituting an engine failure. One railroad, the Chicago and Northwestern, has established uniform practice on its lines in this matter by specifically defining engine failures as follows:

First: All delays waiting for an engine at an initial terminal, except in case where an engine must be turned and does not arrive in time to be despatched and cared for before leaving time.

Second: All delays of engines breaking down, running hot, not steaming well, or having to reduce tonnage on account of defective engine, making a delay at a terminal, a meeting point, a junction, or delaying other traffic.

In connection with this division of efficiency, a statement of the average life of American locomotives, and the amount of time they are unavailable for service, owing to being held for repairs might be not only interesting but pertinent. As to the locomotive's average life, it is generally assumed that a locomotive twenty years old has reached a limit beyond which it is inadvisable to spend much money for maintenance and repairs. In fact, so great have been the strides in the development of power and type, so rapid the displacements, of modern locomotives, that locomotives ten years of age are considered old and are relegated to branch line service. The present tendency is to wear out the locomotive as fast as possible, not, however, by improperly operating or maintaining it, but in as near as practicable continuous work of hauling trains. The amount of time lost by being held for repairs varies considerably, depending on shop and engine terminal facilities; but it is safe to say that the average time lost for making heavy running and class repairs averages from 8 to 10 per cent. of the total life of the locomotive.

C. Operating Costs.—This division of efficiency briefly presents

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some of the costs in locomotive operating, and other relating matter of a more or less statistical nature. The following table shows mileage, costs of maintenance, fuel, etc., compiled from data originally submitted by the several railroads mentioned to the Interstate Commerce Commission for the year ending June 30, 1909:

	Name of Road.						
	P. R. R.	N. Y. C.	L. V.	C. B. & Q.	U. P.	A. T. & S. F.	G. N.
Miles of track	5,307	2,829	1,393	9,022	3,299	5,573	6,923
Number of locomotives owned	4,094	1,894	873	1,676	656	1,612	1,065
Milage, etc.:							
Miles per passenger locomotive	37,000	37,000	33,000	39,000	53,000	27,000	39,000
Miles per freight locomotive	15,000	19,000	19,000	19,000	18,000	19,000	13,000
Miles per total locomotive	24,000	28,000	23,000	27,000	29,000	25,000	23,000
Cost of Maintaining Locomotives:							
Per locomotive mile—cts.	10.2	6.8	10	7.4	11.2	9.8	5.4
Per locomotive—dollars	2,500	1,900	2,250	2,000	3,250	2,500	1,800
Per 1,000 revenue ton miles—dollars	.48	.53	.45	.50	.65	.75	.40
Percentage of maintenance of locomotives to operating expenses	8.8	7	9.6	6	9.4	8.2	6
Percentage of maintenance of locomotives to gross earnings	6.1	5	6	4.2	4.6	5.1	3.6
Cost of Locomotive Fuel:							
Per locomotive mile—cts.	10.2	10.7	14.0	13.2	16.0	12.7	19.5
Per locomotive—dollars	2,450	3,000	3,200	3,550	4,550	3,200	4,300
Percentage of cost of locomotive fuel to operating expenses	8.6	11.2	13.6	10.8	13.4	10.2	14.3
Pounds of freight locomotive fuel per 1,000 revenue ton miles	420	530	530	625	690	670	440

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The following table shows the coal consumed by locomotives, costs, etc., in 1906, compiled from U. S. Geological Survey Bulletin 402:

	Tons	Percentage	Cost
Consumed in starting fires, keeping engine hot while standing and remaining in firebox at end of run	18,000,000	20	$34,100,000
Utilized heat transmitted to water in boiler	41,040,000	45.6	77,700,000
Required to vaporize moisture in coal	3,600,000	4	6,900,000
Lost through incomplete combustion	720,000	0.8	1,350,000
Lost through gases discharged from stack	10,080,000	11.2	19,100,000
Lost through cinders and sparks	8,640,000	9.6	16,360,000
Lost through unconsumed fuel in ash	2,880,000	3.2	5,450,000
Lost through radiation, leakage of steam and water	5,040,000	5.6	9,540,000
Total	90,000,000	100.	$170,500,000
Coal per locomotive per year on basis of 51,000 locomotives in service, 1906	1,760	.....	$3,340

Summary of Efficiency.—Costs are the vital features that determine the successful operation of a railroad. Costs per ton mile, or costs per ton mile per hour, are the bases on which comparison charges are usually made. It is the desire of all railroad companies to transport freight at the lowest cost per ton mile consistent with good service, which can ordinarily best be attained by moving the heaviest trains the locomotives can haul at the required speed. Of course, it is very desirable to economize in the consumption of fuel, but if one extra car can be hauled over the ordinary division at the expense of a ton of fuel, the result is a net gain; or, in other words, true efficiency in locomotive operating embraces not only economy but capacity as well.

To attain the highest efficiency in locomotive operating the following principles are embraced: The locomotive should be of the design and type best adapted to service requirements, constructed of the most suitable material; it should be operated by the engineer and fireman co-operating in skilfully running and firing and taking general good care of it on the road and at terminals.

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PART II

TYPICAL LOCOMOTIVES

CLASSIFICATION OF LOCOMOTIVES, PREVAILING CLASSES AND TYPES, REPRESENTATIVE TYPES, TABLES OF DIMENSIONS AND CHARACTERISTICS.

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CLASSIFICATION OF LOCOMOTIVES.

In railroad transportation, the traffic handled is of two distinct classes: *Passenger* and *freight*. These two classes, which include several sub-divisions each, such as heavy *fast passenger, local passenger, suburban passenger, fast freight,* heavy *through freight* and *local freight,* are conducted by entirely separate departments along very different operating lines.

The steam locomotive is the motive power most generally used for moving these several divisions of traffic, and in the past it has been built in a great variety of forms, though a process of development and elimination has resulted in the production of a few specific types most efficiently adapted to service requirements. Ten to fifteen years ago the representative passenger and freight locomotives were single-expansion locomotives of the American and the Consolidation types. The simplicity of these forms brought them into the widest favor; but the demand for high speed, the hauling of trains of enormous tonnage, and the pressing need of economy in operation has resulted in radical departures from the simple form in recent construction. However, during the progress of development there has been a growing recognition of the fact that the fundamental principles of correct locomotive design must be the same for all types, and so at present there is a country-wide tendency to converge along these lines, though of course some variation in details is at times necessary to meet local conditions.

In the effort to produce not only more efficient locomotives but also to effect greater economy of train operation, the construction of enormously powerful locomotives, boilers of great steaming capacity and the use of high pressure steam, especially on saturated steam locomotives, have been the main contributing features. The introduction of compound cylinders, especially on the balanced and the articulated types of locomotives, improved forms of valve gears, superheaters, brick arches, etc., have also been prominently identified with the development of modern locomotive types, meeting with varying measures of success.

Several different systems, so-called, of the compound principle in locomotive construction have been tried out in this country; but for various reasons, such as unreliability of service, high maintenance costs, etc., not all of which were chargeable directly to compounding features, but were in the main owing to troubles with parts common to both simple and compound locomotives, the popularity of compounds has waned and at the present time there are few of this class running except the balanced and the articulated compound types, and so in

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this part description of compounds will be limited to these two types, especially the articulated type which seems to be rapidly coming into favor.

Compound locomotives must be provided with some mechanism or apparatus for admitting steam, when starting, direct from the boiler to the low pressure cylinders until the exhaust steam from the high pressure cylinders supplies them with steam. The operating of this mechanism or apparatus virtually makes a simple engine of the locomotive, not only enabling the locomotive to start readily, but increases its tractive effort, which is often made use of in emergencies when additional hauling capacity is required for short periods of time. There are two different devices in general use for performing this function. On Baldwin compound locomotives a *by-pass* arrangement is used, while the American Locomotive Co. uses a valve called the *intercepting valve.*

The Baldwin by-pass device is simply a pipe of small cross sectional area attached to each end of the high pressure cylinder, with a valve in it that is operated from the cab. When it is desired to operate the locomotive as a simple engine, the valve is opened, communication is established between both ends of the high pressure cylinder; steam considerably reduced in pressure owing to flowing through the small pipe is admitted to the receiver and from thence to the low pressure cylinders.

The American Locomotive Company's intercepting valve is largely automatic in operation. It is so designed that when the locomotive is working simple the exhaust from the high pressure cylinder passes directly to the atmosphere, the valve cuts off communication between receiver and exhaust side of high pressure piston, and relieves it of back pressure, excepting that of the steam exhausting to the atmosphere. At the same time steam direct from the boiler reduced to a pressure some little above ordinary receiver pressure is admitted to the low pressure cylinder or cylinders. The intercepting valve is located between the receiver and the exhaust passage from the high pressure cylinders. It automatically regulates the pressure of the live steam entering the receiver when starting and also when working simple, keeping it at such a pressure that all cylinders do practically the same amount of work.

Locomotive builders and nearly all railroad companies have their own mode of class designating, suitable to the rules of individual practices, for distinguishing between the various types or modification of type of locomotives built or owned by them. Considerable variation exists in this connection, for a specific system of locomotive classifying has not yet met with general adoption, and so in this book when subjects relate to a particular type of locomotive, unless otherwise stated, the *Whyte System* of *Classification* will be used.

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The Whyte System of classifying locomotives was suggested by Mr. F. M. Whyte as being a method conveniently adapted to classifying locomotives in general, though its application should not be confused with the authoritative locomotive classification in individual use. The Whyte System is based upon the wheel arrangement of the locomotive. Each set of truck, driving, and trailer wheels are grouped and indicated by figures, the grouping beginning at the pilot or head-end of the locomotive. Thus a locomotive commonly known as a Mogul is denoted in the Whyte System by the symbol 2–6–0, a six-wheel switching locomotive by 0–6–0, an Atlantic type by 4–4–2, a Mikado type by 2–8–2, and so on.

The mode of classifying locomotives built by Baldwin's embodies combinations of certain figures with one of the letters A, B, C, D, E, and F, which forms a symbol indicating the number and kind of wheels and size of cylinders, etc. Thus, a locomotive having one pair of driving-wheels is classed B; that with two pairs, C; that with three pairs, D; that with four pairs, E; and that with five pairs, F. The letter A is used for a special class of high-speed locomotive, with one pair of driving-wheels, and also for a type used for rack rail railroads. The initial figures of the symbol, 4, 6, 8, 10, etc., indicate the total number of wheels under the locomotive. A figure or number follows the initial figure from which the diameter of the cylinder can be obtained, and the number following the letter represents the consecutive class number of the locomotive.

The diameters of cylinders can be obtained by dividing the number representing cylinder diameter by two and adding three to the quotient. This number is an arbitrary one, originally intended for another purpose, and in present practice is used as follows: The number 40 represents a cylinder of 23 inches diameter $\left(\frac{40}{2} + 3 = 23\right)$; 38, a 22 in.; 34, a 20 in., and so on. The addition of the fraction ¼ to the symbol indicates that there is a truck placed at each end of the locomotive. The addition of the fraction ⅓ indicates that there is no front truck, but that there is a rear truck placed back of the firebox.

By this mode of classifying, the symbol 10–44–E–100 represents a locomotive with (10) ten wheels; (44) cylinders of 25 in. diameter; (E) four pairs of driving wheels, and (100) the one hundredth of its class built. The same rule is followed in the classifying of compound locomotives, though two numbers, one written over the other, indicate cylinder diameters, the upper number being used for the high pressure cylinder and the lower one for the low: Thus, the symbol

$$16 - \frac{37}{60} - \frac{1}{4} - \text{DD} - 30$$

represents an articulated compound locomotive with (16) sixteen

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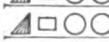
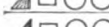
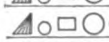
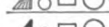
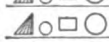
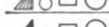
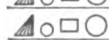
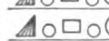
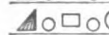
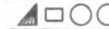
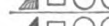
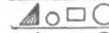
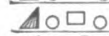
Wheel Arrangement	Type	Whyte Symbol	Baldwin Symbol	P.R.R. Symbol
	4-Wheeled Switcher	0-4-0	4 -C	A
	6-Wheeled Switcher	0-6-0	6 -D	B
	8-Wheeled Switcher	0-8-0	8 -E	C
	10-Wheeled Switcher	0-10-0	10 -F	
		2-4-0	6 -C	
		2-4-2	8¼-C	
		2-4-4	10¼-C	
	Mogul	2-6-0	8 -D	F
	Prairie	2-6-2	10¼-D	J
		2-6-4	12¼-D	
	Consolidation	2-8-0	10 -E	H
	Mikado	2-8-2	12¼-E	
	Decapod	2-10-0	12 -F	
	Santa Fe	2-10-2	14¼-F	
		4-2-2	8¼-A	
	American	4-4-0	8 -C	D
	Atlantic	4-4-2	10¼-C	E
	10-Wheeled	4-6-0	10 -D	G
	Pacific	4-6-2	12¼-D	K
	12-Wheeled	4-8-0	12 -E	
	Sierra or Mountain	4-8-2	14¼-E	
	Mastodon	4-10-0	14 -F	
		0-4-2	6⅓-C	
	Forney	0-4-4	8⅓-C	
		0-6-2	8⅓-D	
	Mallet Articulated	0-4-4-0	8 -CC	
	Mallet Articulated	2-4-4-0	10 -CC	
	Mallet Articulated	2-4-4-2	12¼-CC	
	Mallet Articulated	2-4-6-0	12 -CD	
	Mallet Articulated	4-4-6-2	16¼-CD	
	Mallet Articulated	0-6-6-0	12 -DD	
	Mallet Articulated	2-6-6-2	16¼ DD	
	Mallet Articulated	2-6-8-0	16 -DE	
	Mallet Articulated	0-8-8-0	16 -EE	
	Mallet Articulated	2-8-8-0	18 -EE	
	Mallet Articulated	2-8-8-2	20¼-EE	H-H
	Mallet Articulated	2-10-10-2	24¼-FF	

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wheels; (37) 21½ in. high pressure cylinders, and (60) 33 in. low pressure cylinders; (DD) two groups of four pairs each of driving wheels; (¼) truck at each end of the locomotive, and (30) the thirtieth of its class built.

In the classification of Pennsylvania Railroad locomotives the class of the locomotive is designated by a primary letter and a number to designate the different type of any class, and small suffix letters to indicate some modification of the type. In this mode of classifying, the locomotives are grouped into typical classes according to the number of wheels used under them, irrespective of the service for which they are intended.

The cylinder and wheel arrangement, the typical names, and the designating symbols of these several modes of locomotive classifications are shown in the accompanying table.

PREVAILING CLASSES AND TYPES.

4–4–0 *Type* (*American*).—A locomotive having a four-wheel front truck and four coupled driving wheels, but no trailer. It was the prevailing type of locomotive several years ago used for both passenger and freight service; but as the inherent capacity of the type is low, its design not permitting enlargement beyond certain restricted limits, locomotives of this type have been relegated to branch lines, and main line service where trains are comparatively light.

For high speed service when sufficient adhesion can be secured in a locomotive having two pair of driving wheels, the 4–4–2 type has succeeded the 4–4–0 because of the advantage of the former's greater steaming capacity. Where trains are so heavy that more than two pair of driving wheels are required, the 4–6–0, 4–6–2 and 4–8–2 types are employed.

4–4–2 *Type* (*Atlantic*).—A locomotive having a four-wheel front truck, four coupled driving wheels and a two-wheel trailing truck. This type is a development of the 4–4–0 type of radical departure, virtually a re-design of that type in which the driving wheels are moved forward under the waist of the boiler ahead of the firebox, the main rods being connected to the second pair of closely coupled driving wheels, and a pair of trailing wheels added to support the overhanging back end; resulting in a locomotive, so far as driving mechanism is concerned, quite as simple as the 4–4–0 type, with a boiler of much greater relative steaming capacity. The 4–4–2 type was designed when the weight of train and rate of speed in fast passenger service had attained such proportions that greater horse power was required for sustaining high speed than could be obtained from a 4–4–0 type of practicable design, though all the advantages of a four coupled engine were retained.

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The placing of the firebox behind the driving wheels permits the applying of a wide, deep firebox, of the best form, in which any required grate area can readily be obtained.

The approximate proportions of total weight of locomotive carried by the driving wheels is fifty-five per cent. for the 4–4–2 type, and sixty-six per cent. for the 4–4–0 type, assuming the comparison to be made between two locomotives of these respective types having the same tractive power and weight on driving wheels. On this basis the 4–4–2 type weighs about twenty per cent. more than the 4–4–0, but the greater part of the additional weight is very advantageously utilized in providing a larger boiler, which enables the 4–4–2 type locomotive to maintain high horse power for relatively long periods of time on fast passenger runs or runs of infrequent stops.

4–6–0 *Type* (*Ten-Wheel*).—A locomotive with three pair of driving wheels and a four-wheel leading truck. Used in passenger service where sufficient adhesion cannot be secured from two pair of drivers, and ordinary boiler capacity suffices. Also used to considerable extent in fast freight service.

4–6–2 *Type* (*Pacific*).—A locomotive with a four-wheel front truck, six coupled driving wheels and a two-wheel trailing truck. Used for heavy, fast passenger service of such character that the required tractive effort necessitates the use of three pair of drivers in order to secure sufficient adhesion without overloading the rails, and boilers of great steaming capacity are required to sustain speed.

4–8–2 *Type* (*Mountain*).—A locomotive with a four-wheel front truck, eight coupled driving wheels and a two-wheel trailing truck. Of recent introduction in heavy passenger service on mountain grades.

Balanced Types (Built with several different wheel arrangements, including 4–4–2, 4–6–0, 4–6–2, and 2–6–2).—Balanced locomotives all are of two classes, simple and compound. Both classes have four cylinders; two being placed between the frames, and the other two placed outside the frames in the usual manner. The pistons of the cylinders between the frames are connected to cranks on a crank axle, while those of the outside cylinders are connected to pins on the outside of the driving wheels in the ordinary way.

There are two builds of balanced compound locomotives, the Baldwin, and the Cole (Schenectady). The compounding principle of both have about the same general characteristics, though there is a slight difference in the location of cylinders and in the arrangement of driving gear. In this class the high pressure cylinders are located between the frames and the low pressure cylinders outside. The Cole type has the high pressure cylinders placed somewhat ahead of, and between the low pressure cylinders, with the high pressure guides over the truck; while the Baldwin has all cylinders in line across the locomotive with both sets of guides back of the cylinder casting.

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When practicable, which is usually the case, all cylinders in both classes are horizontal, the crank centers of the axle crank and the wheel pin on each side of locomotive are placed one hundred and eighty degrees apart, and ninety degrees from corresponding cranks on opposite side of locomotive. With pistons connected in this manner they oppose each other in movement, for on each side of the locomotive they start their strokes from opposite ends of their respective cylinders at the same instant; the effects of the moving reciprocating parts are neutralized, so that excessive weight for counterbalancing is not required, and the forces developed in the cylinders being approximately equal and in opposition, a balanced condition is obtained. Balanced locomotives are used in both passenger and freight service.

2–6–0 *Type* (*Mogul*).—A locomotive having a two-wheel front truck and six coupled driving wheels.

2–8–0 *Type* (*Consolidation*).—A locomotive having a two-wheel front truck and eight coupled driving wheels. Used for heavy freight service, and until recently was practically the only locomotive in that service.

2–6–2 *Type* (*Prairie*).—A locomotive with a two-wheel front truck, six coupled driving wheels and a two-wheel trailing truck. Used principally for heavy fast freight service, though used to some extent in passenger service.

2–8–2 *Type* (*Mikado*).—A locomotive with a two-wheel front truck, eight coupled driving wheels and a two-wheel trailing truck. Used for heavy freight service.

The 2–8–2 Type is a development of the well known 2–8–0 on lines very similar to the change from the 4–4–0 to the 4–4–2 type, the principal change being the addition of a two-wheeled trailing truck. As in the latter two types, the 2–8–2 was designed with the object in view of securing a locomotive of the greatest tractive effort and a boiler of greatest steaming capacity permissible with its particular wheel arrangement. In the 2–8–2, as in the 4–4–2 and 4–6–2 types, the firebox can be placed entirely behind the driving wheels, thus giving a large grate area and a greater depth of furnace than can be secured in a locomotive of the 2–8–0 type. This latter feature permits the firebox being designed to burn lignite coal and other fuels of low grade, which is a distinct advantage in parts of the country where the poorer fuels are plentiful.

Mallet Articulated Types (Built with several different wheel arrangements, but the prevailing types are of the 0–6–6–0, 2–6–6–2, 0–8–8–0 and 2–8–8–2 order).—A locomotive having two sets of cylinders driving independent groups of wheels under two separate frames joined by a flexible connection, built in both the simple and compound classes.

The Mallet articulated compound locomotive is composed of two

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half units, each having a set of cylinders driving independent groups of wheels under separate frames, which are joined in tandem by an articulated connection.

The frames of the rear half unit are held in rigid alignment with the boiler, though the frames of the front one are movable, swinging about the fulcrum pin of the articulated connection and virtually form a truck under the forward part of the boiler. The weight of the locomotive is equalized on the two groups of wheels by contact between the frames at the point of connection. The forward part of the boiler rests on sliding supports, which are fitted with centering springs that tend to preserve alignment of the forward group of wheels. It may be seen that the front group swings radially about its articulated connection with the rear group, when the locomotive passes through a curve. It is from this jointed frame feature that the articulated type of locomotive derives its name. The rigid wheel base of the Mallet type is that of the rear group of driving wheels only, which is usually less than that of large six or eight coupled locomotives in general use, and no difficulty is experienced in having them traverse the sharpest curves encountered on main trunk lines. As the total number of wheels is greater than in ordinary types of even larger locomotives, and their weight is distributed over a greater number of axles, an enormous weight with correspondingly great tractive effort may be provided in this type without imposing excessive weight per wheel on the rail. An articulated compound locomotive may have twice as many driving wheels and double the tractive effort of a given ordinary locomotive of rigid frame type, and yet have the same weight per wheel on the rail with no greater rigid wheel base than the latter.

The sub-division of power among four main rods instead of two, permits the use of much lighter parts, facilitates their handling on the road and in shops, and also results in reducing to a minimum the pressure on crank pins and shocks to driving boxes and frames.

In addition to advantages of wheel arrangement, articulated compound locomotives possess the further advantage resulting from compounding of steam. The compounding feature of this type of locomotive is what is known as two-stage, that is, the steam is used successively in two sets of cylinders.

The high pressure cylinders are usually attached to the rear frames, the low pressure cylinders being attached to the front frames. The high pressure cylinders usually receive steam from the boiler through external, rigidly connected steam pipes. Steam from the boiler is admitted to the first set or high pressure cylinders, which ordinarily drive the rear group of wheels; and, having done work in those cylinders, is then used over again in the second set or low pressure cylinders which are connected to the front group of wheels. From

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the low pressure cylinders, the steam is exhausted to the atmosphere.

Between the high and low pressure cylinders and connecting the two is a large pipe called the receiver into which the steam from the high pressure cylinders exhausts when the locomotive is working compound. The receiver is simply a reservoir in which the exhaust steam from the high pressure cylinders is stored until it is required by the low pressure cylinders. From the receiver, the steam is admitted into the low pressure cylinders by their valves in the usual manner.

The low pressure cylinders have a larger piston area than the high pressure cylinders, the ratio between the two being such that, at the ordinary working cut-off, the steam at the lower pressure per square inch acting against the larger piston area, exerts the same force as the higher pressure steam acting on the smaller area. Consequently, the high and low pressure cylinders having the same stroke, each set of cylinders ordinarily does practically the same amount of work.

In developing the Mallet articulated type the Baldwin people have introduced several features entirely new in locomotive construction, especially on recent productions of the heavier types. Some of these innovations have proved improvements of practical value, the most important of which may be described as follows:

A sectional boiler, of separable connection, with the evaporating portion in the rear section and the front section forming a feed-water heater. The feed-water heater is traversed by fire tubes similar to boiler tubes, and when the locomotive is in service it is kept constantly full of water, which overflows through a connecting feed pipe into the rear section or boiler proper, when the injectors are operating. The separable boiler joint is placed just in front of the articulated frame connection, surrounding an intermediate combustion chamber, and so the locomotive, including the boiler, can readily be separated into two sections, thus facilitating the handling of parts when making repairs. Superheaters, for superheating the steam before admission to the high pressure cylinders, and reheaters, for reheating (virtually superheating) the steam released from the high pressure cylinders before admission to the low, have been applied.

The American Locomotive Company has not adopted the plan of a sectional boiler of the separable type, though it has practically become the rule to install superheaters in articulated locomotives designed by them. This company has built at least one Mallet articulated locomotive, for a prominent railroad, of the simple or single-expansion class for experimental purposes. It is equipped with a fire tube superheater that superheats to a high degree the moderately high steam pressure carried. This locomotive is of very large dimensions, capable of exerting a tractive effort of approximately 100,000 pounds, and when worked to its full capacity consumes coal at a rate of about 10,000 pounds per hour. Owing to physical limitations a man would be

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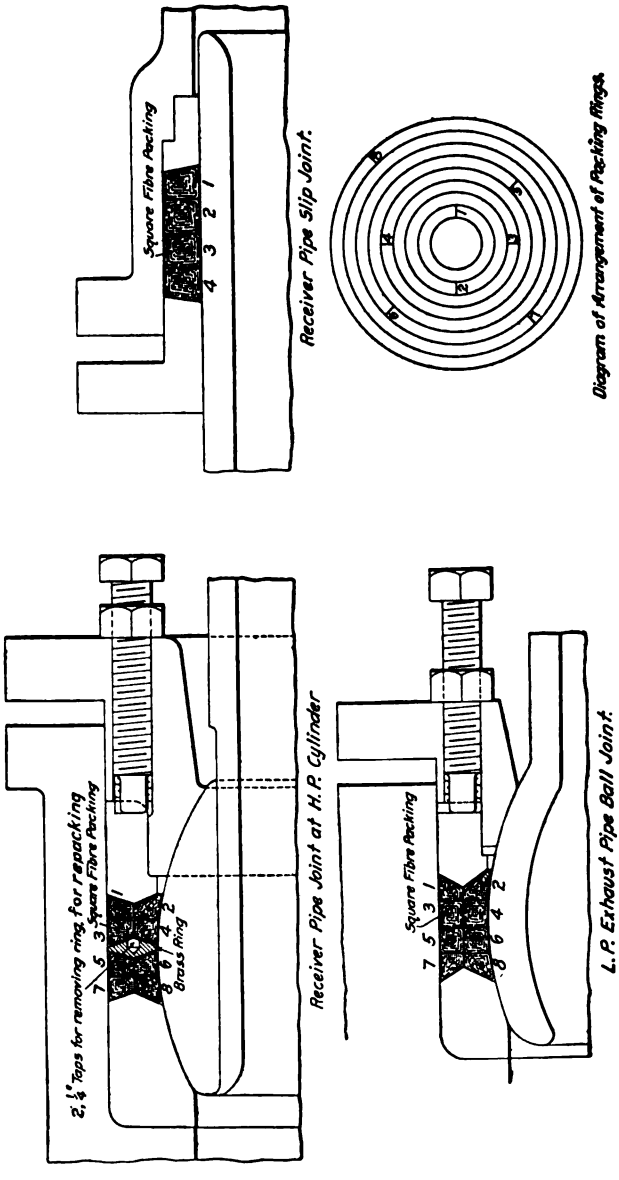

FIG. 5.—Flexible steam pipe joints.

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unable to fire coal at such a rate for any length of time, and so this locomotive is equipped with a mechanical stoker, of the underfeed type, which promises to be a practical success. This locomotive was built for the purpose of making tests and comparing its performance with that of articulated types of the compound class, with the view of adopting the more efficient class in future builds, it being the thought of many engineers that, everything considered, simple locomotives carrying

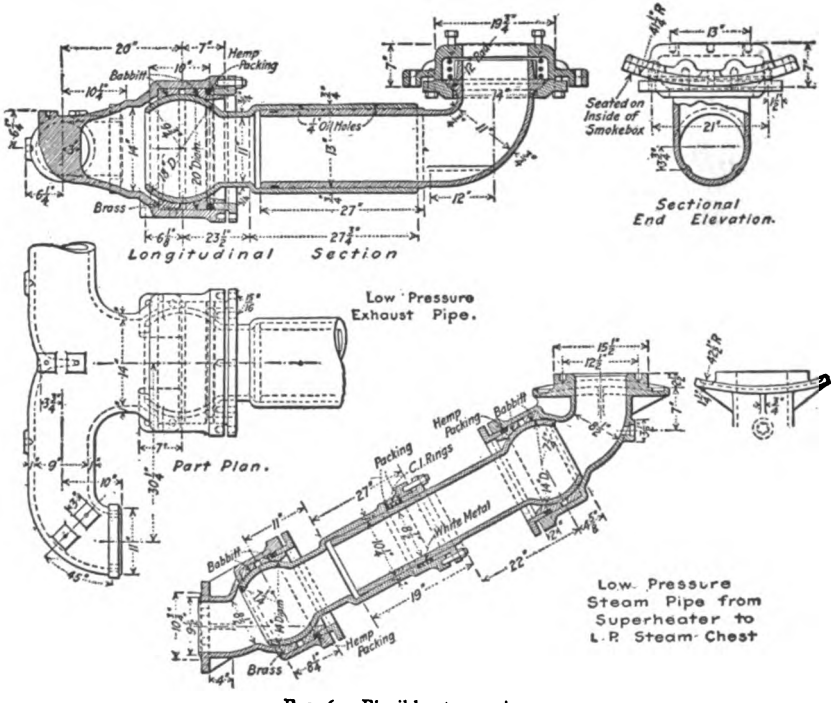

FIG. 6.—Flexible steam pipes.

moderately high steam pressure superheated to a high degree should prove more efficient than the compound class.

Owing to the front frame swinging radially about its articulated connection, it is necessary for all piping passing between the front and rear frames to have flexible connections, which is accomplished by ball and slip joint connections in steam and receiver pipes. These ball joints consist of a ball-bearing, gland, stuffing box and packing; while in the slip joints, the construction is very much the same, without the ball-bearing. The packing in the joints of the American locomotives consists of a fibrous material, while the Baldwin's have both fibre

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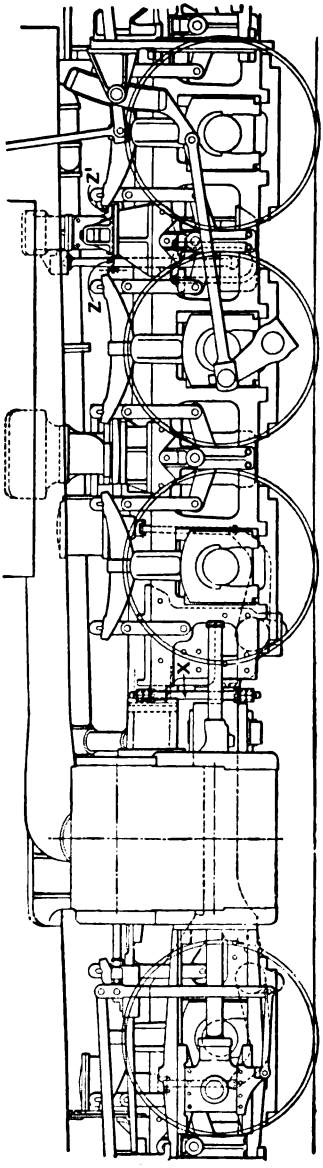

FIG. 7.—Trim bolts.

and soft metal packing in their flexible connections.

The American articulated compound locomotive has a ball joint connection between the receiver pipe and the high pressure cylinders, a slip joint connection between the receiver pipe and the Y-pipe by which the steam is carried to the steam passages of the low pressure cylinders, a ball joint connection between the exhaust pipe flexible connection and the low pressure cylinders, and also between the former and the exhaust pipe in the smoke box. This exhaust pipe flexible connection is likewise provided with a slip joint to allow for the variations in its length when the engine rounds a curve. The construction of these flexible connections is shown in Fig. 5. In the Baldwin articulated compound locomotives there is some little difference in piping arrangements owing to the use of superheaters and reheaters, but the same principle in the use of flexible, ball and slip joints is followed. The Baldwin's system of flexible connections is shown in Fig. 6.

In the American articulated locomotives, vertical hanger or "trim" bolts (x), Fig. 7, connect the upper rails of the rear frames with the lower rails of the front frames. These bolts have ball and socket bearings in the frame rails, and sufficient play is allowed in the bolt holes to provide for the lateral movement of the front frames when the locomotive is passing through a curve. They serve to adjust the weights on the front and rear half units so that each bears its proportionate amount of the total load, and to keep the front frames in proper alignment.

The Baldwin form of articulated connection employs a single radius bar, consisting of a steel casing bolted to the

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rear end of the front frames. Hanger bolts are omitted in this design, and the rails of the rear frames are extended forward between the upper and lower rails of the front frames, a slight amount of vertical clearance being provided. Equalization of load between the two half units is effected by actual contact between the frames at this point. This form of connection is shown in Fig. 8.

As an experiment, articulated locomotives with an articulated boiler connection have been built. In this form of construction the front section of the boiler is rigidly mounted on the front frames, curving with them when necessary; and the rear section is attached to the

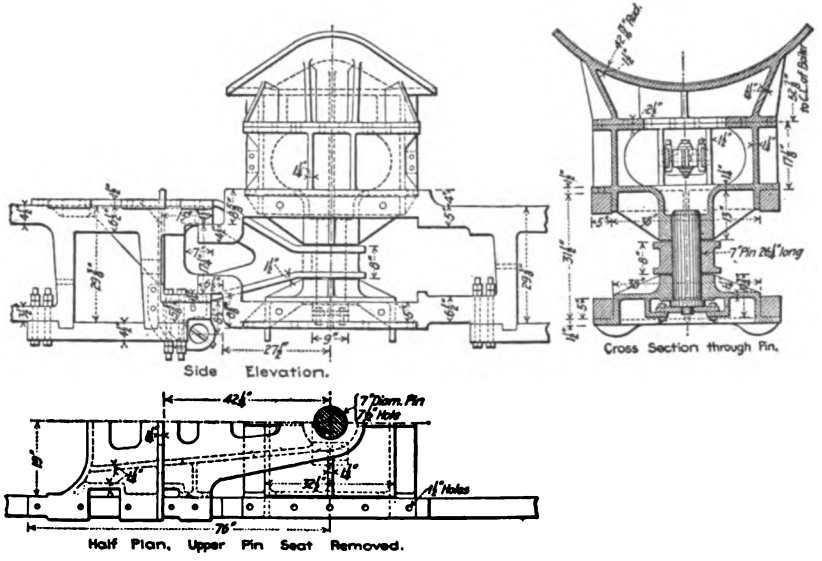

FIG. 8.—Articulated frame connection.

rear frames in the ordinary manner. On these locomotives it is necessary, of course, to place flexible connections in all pipes passing the articulated connection on both boiler and frames.

As stated previously, it is usually necessary when starting, and also at other times under certain circumstances, to admit steam direct from the boiler to the low pressure cylinders of compound locomotives. In the Baldwin articulated compound this is accomplished by an arrangement very similar to the by-pass device, applied to the Vauclain and the balanced compound types. It consists of a pipe of small cross-sectional area connecting the high pressure steam and the receiver pipes, having a cock or valve in it operated from the cab.

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Intercepting Valve.—(Applied to Articulated Compound Locomotives, American Locomotive Company.)—The intercepting valve as applied to American Locomotive Company's articulated compound locomotives is identical in principle with that used on their well-known two-cylinder cross-compound locomotives, commonly known as the Richmond Compound, differing from the latter only in certain modifications of the design which the use of four cylinders instead of two necessitates. Engineers, therefore, who have operated the two-cylinder cross-compound of this build will be perfectly familiar with the con-

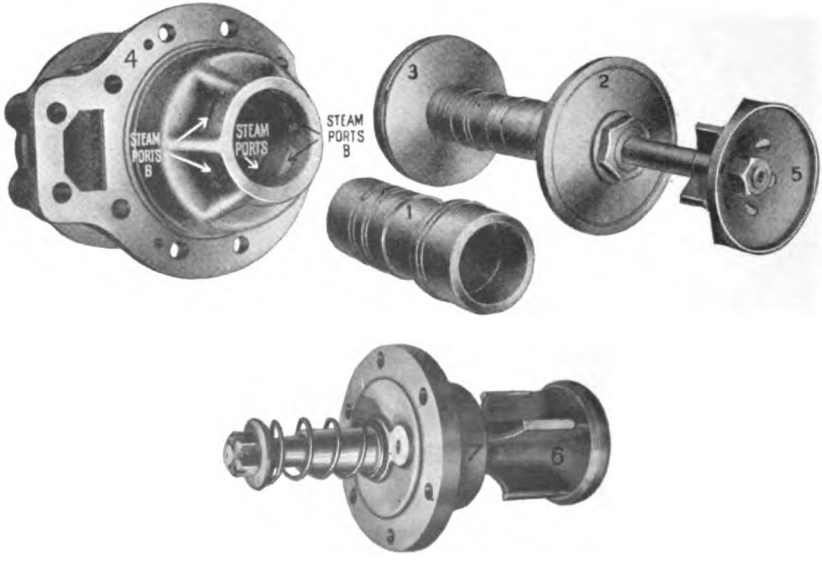

FIG. 9.—Parts of intercepting valve.

struction and operation of the intercepting valve as applied to the American articulated compound locomotive.

This valve is located in the saddle of the left high pressure cylinder, to the left of the vertical and above the horizontal center line of the cylinders. It consists, in reality, of three valves, viz., the intercepting valve, the reducing valve or sleeve, and the emergency or high pressure exhaust valve.

The various parts comprising the whole mechanism are shown in detail in Fig. 9. Each part is designated by a number for reference.

Parts 2, 3 and 5 constitute the intercepting valve proper. The intercepting valve shuts off, at the proper time, communication between the receiver and the high pressure cylinders to prevent the pressure

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in the receiver backing up against the high pressure pistons, when the locomotive is working with live steam in all four cylinders.

The reducing valve or sleeve (1) fits on the stem of the intercepting valve (2), along which it is free to slide longitudinally. Its duty is threefold:

First, to close the intercepting valve in starting and when the locomotive is changed from compound to simple;

Second, to let live steam from the boiler into the receiver and low pressure steam chests in starting and also when the locomotive is working simple;

Third, to regulate the supply of this live steam and keep its pressure at a predetermined point.

The emergency or high pressure exhaust valve (6), which is located at one of the outer ends of the intercepting valve chamber, is the device which makes it possible to change the locomotive from compound to simple (that is, use live steam in all four cylinders).

A wrought iron pipe leads from the emergency valve chamber along the left side of the locomotive to an elbow at the rear of the main exhaust pipe. This elbow connects with a passage surrounding the main exhaust opening.

When the locomotive is changed into a simple engine, the emergency valve (6) is opened, which allows the exhaust steam from the high pressure cylinders to pass through the wrought iron pipe to the exhaust pipe in the smoke box and to the atmosphere.

The opening of the emergency valve is accomplished by opening the emergency operating valve which is indicated by the letter (N) in Fig. 10. When the emergency operating valve is closed (or, in other words, when the locomotive is compound), the handle of the valve points FORWARD. To open the emergency operating valve (N) and change the locomotive into simple, the handle must be turned so as to point BACKWARD. The opening and closing of the emergency valve (6) is thus under the control of the engineer.

It is important to bear in mind that the emergency valve, as its name indicates, should ordinarily be used only when the locomotive cannot otherwise move the train; and, as soon as a speed of three to four miles per hour has been attained, the locomotive should be changed back to compound.

Except for changing the locomotive into simple, the movements of all the parts of the intercepting valve are automatic.

The illustrations in Fig. 11 show the entire mechanism assembled, and the arrangement of the various steam pipes and passages. These illustrations also give the intercepting valve in its four different positions, namely:

First, position 1, the moment after the throttle is open when start-

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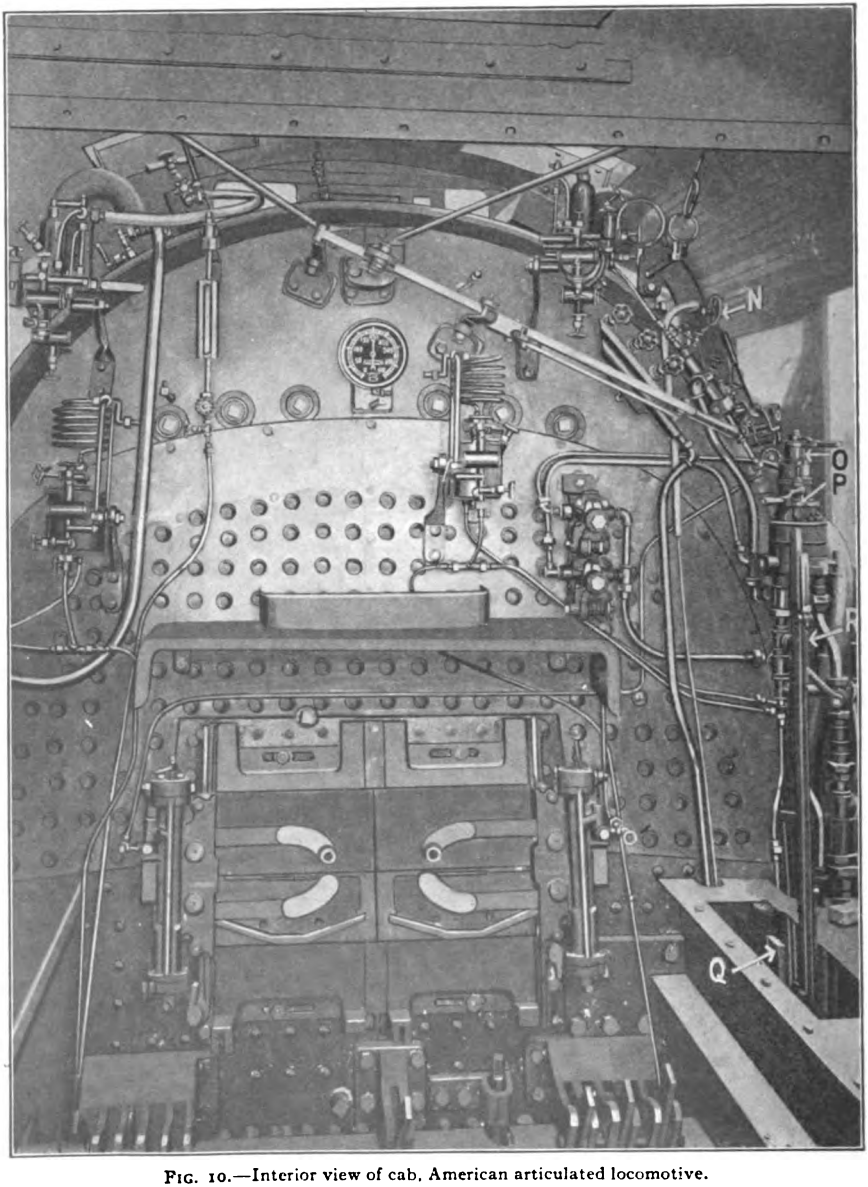

FIG. 10.—Interior view of cab, American articulated locomotive.

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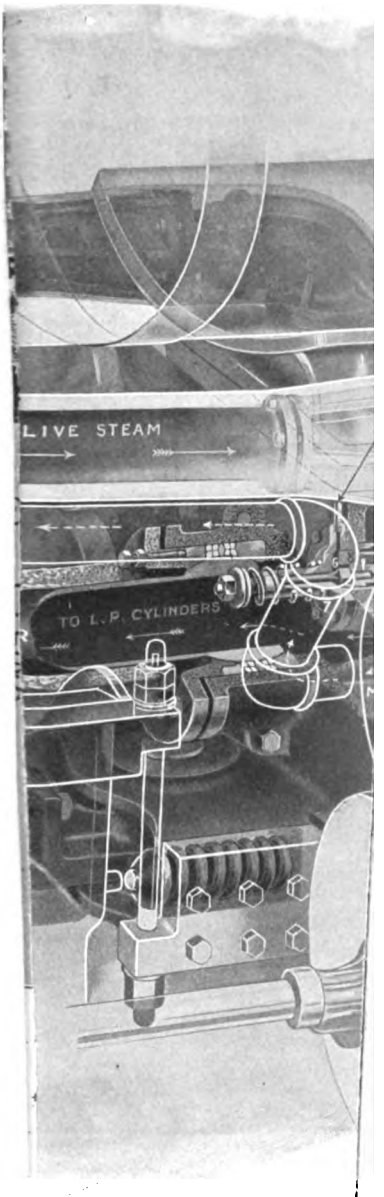

) IN ORDINARY WAY.

essure pistons start free from b.

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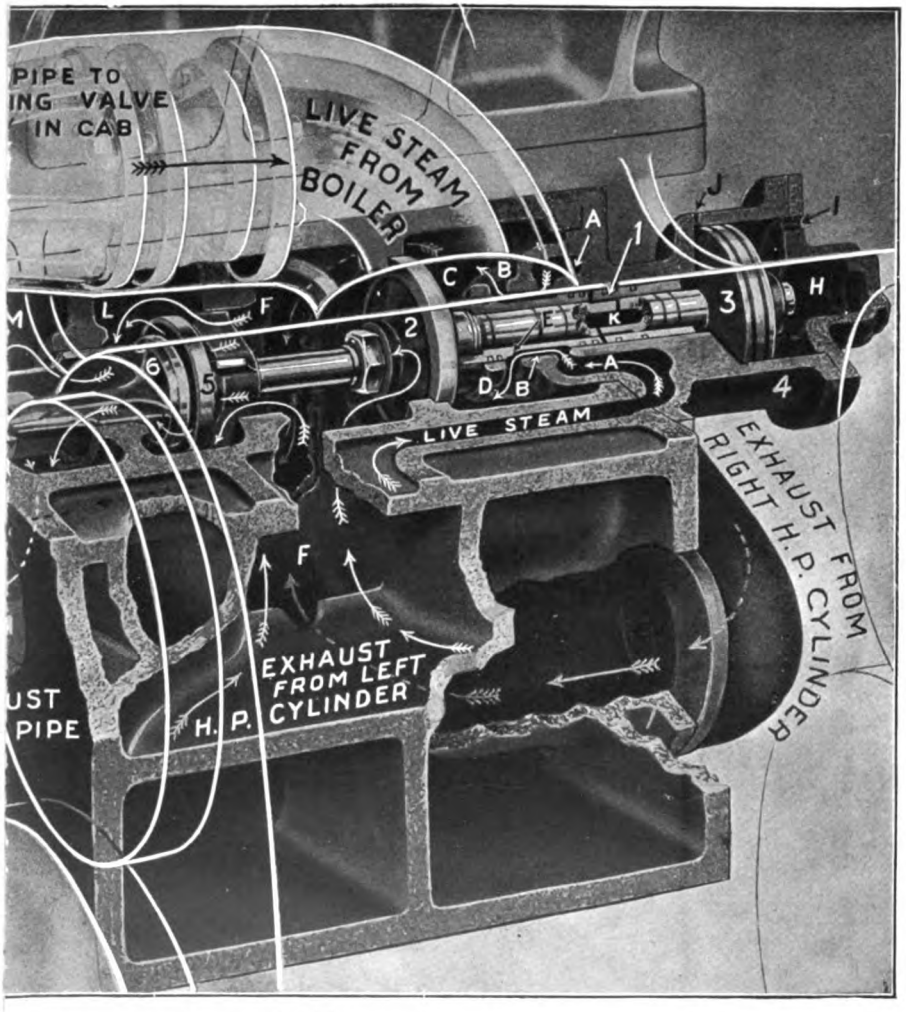

FIG. 11—Position 4.

INTERCEPTING VALVE IN SIMPLE POSITION.

cing Valve (1) are open and Intercepting Valve (2) is closed. The exhaust from the high sed to the atmosphere, the high pressure cylinders are relieved of receiver pressure m is admitted to all cylinders, giving 20% increase in tractive power.

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ing in the ordinary way, the reducing valve (1) being open and the intercepting valve (2) and the emergency valve (6) closed.

Second, position 2, at the time when the predetermined pressure has been reached in the receiver pipe, when the reducing valve (1) is closed and the other parts remain the same as in position 1.

Third, position 3, in the compound position, when the intercepting valve (2) is open and the reducing valve (1) and the emergency valve (6) are closed.

Fourth, position 4, in simple position, when the emergency or high pressure exhaust valve (6) and the reducing valve (1) are open, and the intercepting valve (2) is closed.

In the illustrations, the course of the steam is indicated by arrows. As will be seen from Fig. 11, the reducing valve (1) is so fitted on the stem of the intercepting valve (2) that when the former opens it closes the latter and *vice versa*. The reducing valve, however, can be closed without opening the intercepting valve.

Operation of the Intercepting Valve.—Referring to Fig. 11, live steam from the boiler is, as indicated by the arrows, always admitted through the passages in the cylinder casting to the chamber (A) formed in the intercepting valve chamber head (4) and surrounding the reducing valve (1). Chamber (C) communicates with the receiver pipe or steam passage to the low pressure cylinders, and chamber (F) connects directly with the exhaust passages from the high pressure cylinders. The chamber (L) communicates with chamber (M) through the emergency or high pressure exhaust valve (6). The latter chamber is connected with the exhaust pipe in the smoke box, as previously explained.

With the intercepting valve in the position shown in position 1 of Fig. 11, steam from the boiler, following the course of the arrows, flows through the passage in the left high pressure cylinder to chamber (A) and acting against the shoulder (E) of the reducing valve (1), has forced this valve open or inward, closing the intercepting valve (2) and uncovering the ports (B). This allows live steam to pass into the chamber (C), and thence into the receiver and to the low pressure steam chests and cylinders. Live steam, at the same time, passes through the high pressure valves into the high pressure cylinders in the ordinary way. The intercepting valve (2) being closed, communication between the exhaust passage (F) from the high pressure cylinders and the chamber (C) is cut off. This thus prevents the pressure in this latter chamber from backing up against the exhaust side of the high pressure pistons; and, consequently, these start free from back pressure; while, at the same time, the low pressure cylinders are being supplied with steam direct from the boiler. The pressure of this steam is so regulated by the reducing valve (1) that it bears the same relation to the boiler pressure as the high pressure piston

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areas bear to the low pressure piston areas, thus making the work in all four cylinders equal (the high and low pressure cylinders having the same length of stroke). For instance, if the area of the low pressure cylinder is two and one-half times the area of the high pressure cylinder, then the reducing valve (1) would be so designed as to reduce the pressure of the live steam admitted by it to chamber (C), to $1 \div 2.5$ or 40 per cent. of the boiler pressure.

From the above it will be seen that the locomotive automatically starts with live steam in all four cylinders, or, in other words, as a single expansion engine.

Piston (3) and the chamber (H) in the outer end of the intercepting valve chamber head (4) constitute simply an air dash-pot, to prevent slamming of the valves when changing from compound to simple running.

Position 2 in Fig. 11 represents the intercepting valve at the moment when the predetermined maximum pressure in the low pressure steam chests is reached. In this case it will be noticed that the positions of the valves are the same as in position 1, except that the reducing valve (1) has been moved out, closing the ports (B), thus cutting off the supply of live steam to the chamber (C), and to the low pressure steam chests, until by the movement of the low pressure pistons the pressure in that chamber has been lowered to the required point.

The reducing valve (1) automatically keeps the pressure in the chamber (C) down to the desired amount because of the fact that the area of the shoulder (E) is, as previously stated, usually $1 \div 2.5$ or 40 per cent. of the area of the end (D) of the valve. Consequently, when the pressure in the chamber (C) exceeds 40 per cent. of the boiler pressure, it will overcome the force of the steam at boiler pressure, acting on the shoulder (E), and move the reducing valve (1) outward, closing ports (B).

The intercepting valve automatically assumes position 3, the compound position, after one or two revolutions of the driving wheels. In this position the intercepting valve (2) is opened, allowing the exhaust steam from the high pressure cylinders to pass into the chamber (C), and so to the receiver and the low pressure cylinders. The opening of the intercepting valve (2) has closed the reducing valve (1), which thus cuts off the supply of live steam to the chamber (C) and receiver.

The principle by which these movements are automatically performed may need explanation. The exhaust steam from the high pressure cylinders in the chamber (F) acting against the inner face of the intercepting valve (2) and also against the inner end of the intercepting valve stem, being admitted to the chamber (L) through the holes in the unbalancing valve (5), tends to open the intercepting valve

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(2). This force is resisted by the pressure on the outer face of the intercepting valve (2), the pressure on the outer and inner faces of the unbalancing valve (5) being balanced. The combined areas of the face of the intercepting valve (2) and the end of its stem are greater than the area of the outer face of the valve. Thus steam in the chamber (F) at a lower pressure acting against this larger area overcomes the resistance of the higher pressure steam in chamber (C) and forces the valve into the position shown. This principle is the same as in the case of the reducing valve previously explained.

These areas are usually so proportioned that when the pressure in the chamber (F) is 30 per cent. of the boiler pressure, it overcomes the resistance of the steam in the chamber (C) at a pressure of 40 per cent. of boiler pressure.

As will be seen from the preceding, when the locomotive is working compound the low pressure steam chests receive all of their steam from the exhaust from the high pressure cylinders through chambers (F) and (C) and the receiver, the ports (B) having been closed by the outward movement of the intercepting valve (2). At full stroke, the pressure on the low pressure pistons would be, approximately, 30 per cent. of the boiler pressure; while, on the high pressure pistons, would be exerted the pressure which the live steam from the boiler has, minus the 30 per cent. in the receiver which acts on their exhaust sides. The work performed in each of all four cylinders is practically equal, as the products of the several piston areas multiplied by their respective pressures are equal in each case.

Should the maximum power of the locomotive be required in starting or in ascending a heavy grade, it may be had at any time by simply turning the emergency operating valve (N) in the cab so that the handle points BACKWARD. The intercepting valve will then assume the position shown in 4, Fig. 11.

Opening the emergency operating valve admits live steam into the chamber (G) which forces the emergency valve (6) open against the resistance of its own spring plus the pressure of steam in the chamber (L) (which is receiver pressure).

On the opening of the emergency exhaust valve (6), the steam in the chamber (L) is immediately released. This unbalances the intercepting valve (2) with the result that the reducing valve (1) is moved inward or opened by the pressure of the steam from the boiler in chamber (A) acting against the shoulder (E). The reducing valve (1) carries the intercepting valve (2) inward with it, closing the latter, the two valves assuming the position shown in position 4. Communication between the chamber (C) and the chamber (F), into which the steam from the high pressure cylinders exhausts is thus cut off; while live steam from the boiler, at a pressure reduced to about 40 per cent. of the boiler pressure, is allowed to pass through the ports (B) into

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the chamber (C) and thence through the receiver to the low pressure steam chests.

By the use of the intermediate chamber (L) between the chamber (F) and the emergency valve (6), which is exhausted the instant that valve is opened, the intercepting valve (2) is closed and the reducing valve (1) opened before, or at the same moment, that the receiver is actually exhausted. Consequently, there is no drop of pressure in the low pressure steam chests during the change from compound to simple or prior to the entrance of live steam into the low pressure steam chests.

As the emergency exhaust valve (6) is kept open by the pressure of the steam admitted to the outer side of the piston (8) by the opening of the emergency operating valve in the cab, the exhaust steam from the high pressure cylinders passes through the chamber (F) into the chambers (L) and (M) and so into the high pressure exhaust pipe and to the atmosphere.

Thus when the intercepting valve is in position 4—that is, when the locomotive is working simple, the high pressure pistons are relieved if the back pressure amounting to 30 per cent. of the boiler pressure, which acts against them when the locomotive is working compound, with the intercepting valve in position 3. On the other hand, the low pressure cylinders are receiving steam direct from the boiler at a pressure of 40 per cent. of that in the boiler, instead of exhaust steam from the high pressure cylinders at a pressure of only 30 per cent. of boiler pressure as when the locomotive is working compound. This explains the increase in normal maximum power obtained by changing the locomotive into simple, which amounts to about 20 per cent. increase. The increase would be greater were it not for the wire-drawing of the steam through the restricted area of the ports (B), which are intentionally reduced for operation under this condition. As it is, the actual increase in power at speeds of from three to four miles per hour would not be greater than the amount given above.

The reducing valve (1) is so designed that at speeds of more than three or four miles an hour no increase in power is obtained by changing the locomotive into simple. This is done in order that the emergency feature will not be misused, with injurious effect on the machinery and the sacrifice of economy in fuel consumption.

If the pressure in the chamber (C) and consequently in the receiver pipe and the low pressure steam chests rises to more than 40 per cent. of the boiler pressure when the engine is working simple, the reducing valve (1) will be forced outward to the position it has in 2, that is closing the ports (B) and shutting off the live steam from the chamber (C). The other parts of the valve, however, will remain in the same position as shown in 4. The reducing valve (1) automatically closes under the conditions as previously stated.

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Upon the movement of the low pressure pistons, the steam pressure in the chamber (C) will be reduced; and the boiler pressure acting upon the small shoulder (E) would again force the reducing valve (1) inward to its position in 4, opening the ports (B). Thus the pressure in the chamber (C) and low pressure steam chests would be again raised to the required 40 per cent. of the boiler pressure. This alternate opening and closing of the reducing valve (1) will continue as long as the displacement of the low pressure pistons does not exceed the supply of steam that comes through the ports (B). When this condition occurs, the reducing valve (1) will remain open.

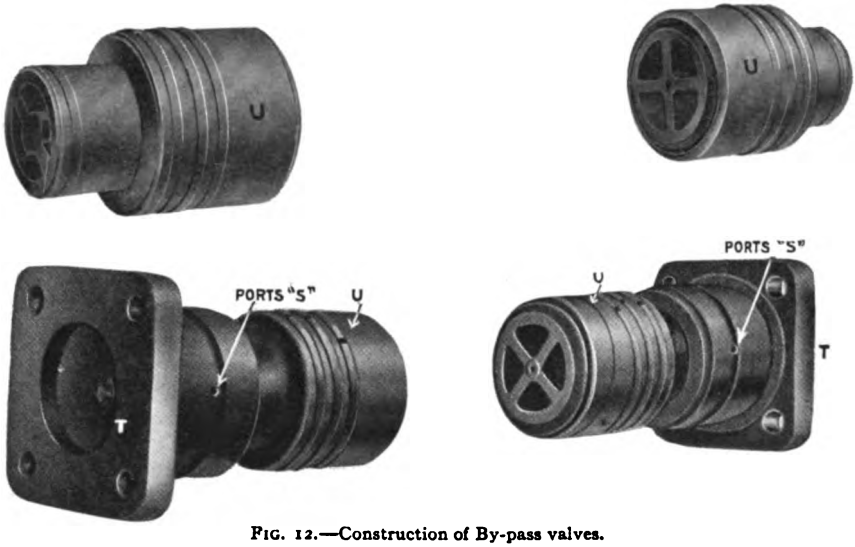

FIG. 12.—Construction of By-pass valves.

These facts explain why, if the locomotive starts to slip when it is changed into simple, it automatically ceases without necessitating closing the throttle; since, with the rapid movement of the low pressure pistons the power of these engines is reduced; and, with the increased exhaust from the high pressure engines passing through the comparatively restricted opening of the emergency valve (6) the back pressure on the high pressure pistons is increased, reducing the effective power in these cylinders.

All of the ports of the intercepting valve have important duties to perform, and their location and sizes must not be changed.

By-Pass Valves (American Locomotive Company's Articulated Compound Locomotives).—The purpose of by-pass valves in American articulated locomotives is to prevent the injurious effects that would

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otherwise result from the pumping action of the large low pressure pistons when the locomotive is drifting. They are so designed that they automatically establish communication between the two ends of the cylinder, when the engine is running with the throttle closed, thus performing several important functions.

First, they prevent alternating vacuum and compression in the cylinders when the locomotive is drifting, thus insuring the free movement of the pistons.

Second, by permitting the circulation of the free air drawn into the cylinders through the vacuum-relief valves, they prevent this air from being overheated by the churning of the pistons and thus destroying the lubrication when the locomotive is drifting long distances.

Third, by destroying the vacuum that, without them, would be formed by the large piston, they prevent the smoke and gases from the smoke box being drawn into the cylinder.

Fourth, they prevent excessive fanning of the fire from the pumping action of the large pistons when drifting.

These valves are located in chambers cast in the outside of each low pressure cylinder. Their construction is shown in Fig. 12. There are two valves to each cylinder. The lower view in the illustration shows the two valves (U) with the heads (T) of the chambers in which they are located; while the upper view shows the valves alone without the valve chamber heads.

Fig. 13 illustrates the arrangement of the valves when assembled in their chamber and their relation to the steam ports in the cylinders.

In position A of this latter figure, the valves (U) are in the position they assume when the throttle is open. In this position, the steam passing from the steam chest ports through the small ports (S) in the head (T) of the valve chamber, as indicated by the arrows, acts against the outer ends of the valves (U) and keeps them against their seats, cutting off communication between the admission ports of the cylinders.

Position B of Fig. 13 is the one the by-pass valves (U) automatically take when the throttle is closed, when atmospheric pressure is admitted through the small air vent in the valve chamber forcing the valves (U) open, closing the steam chest ports and establishing communication between the admission ports at both ends of the cylinders. This permits circulation from one end of the cylinder to the other when the locomotive is drifting.

In order to have the locomotive drift freely the best practice is to place the reverse lever at a point that would give cut-off at three-quarter stroke or later.

It is important that the by-pass valves be properly cared for and kept in good condition to prevent them from sticking. The engineer

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can tell at once if the by-pass valves are stuck open; as, in that case, steam will blow from the small pipe projecting from under the jacket midway between the ends of the cylinder. This pipe connects to the air vent in the center of the chamber containing the valves. From this description it will be seen that if the by-pass valves stick open it will cause a severe blow.

If the low pressure engines are heard to thump as if a piston, crosshead or box were loose and the locomotive does not drift freely, the trouble probably lies in the by-pass valves being stuck closed by being gummed; and they should be taken out and cleaned at the first opportunity.

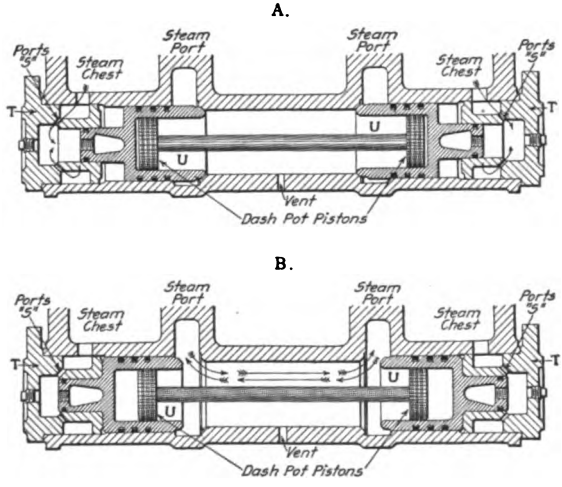

FIG. 13.—By-pass valves in closed and open positions.

Sticking of the by-pass valves may be caused by smoke box gases being drawn into the cylinders by the pistons when the locomotive is drifting with the reverse lever "hooked up," and the soot deposited on the oily surfaces of the by-pass valves and seats.

Vacuum and Relief Valves (American Locomotive Company's Articulated Compound Locomotives).—In the American Locomotive Company's articulated compound locomotives vacuum valves are located in the high pressure steam chests or some other convenient place in communication with the steam chests. The function of these valves is to admit free air into the steam chests when the locomotive is drifting so as to avoid a vacuum and give a moderate flow of air through the cylinders.

The low pressure cylinders are equipped with combined vacuum and relief valves which in addition to having functions similar to the

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vacuum valves of the high pressure cylinders also regulate the steam pressure in the low pressure steam chests.

From the previous description of the intercepting valve it will be seen that when the locomotive is working compound the packing rings of the high pressure valves and pistons alone separate the boiler pressure from the pressure in the receiver and low pressure cylinders. Consequently, if there is a blow in these packing rings, the pressure in the receiver will increase, causing the relief valves in the low pressure steam chests to blow-off. If these valves rise from their seats frequently when the locomotive is working compound, it may be due to the fact that there is a blow in either the valves or the pistons of the high pressure cylinders; and these should be tested.

To test for blows, throw the emergency operating valve in the cab to the simple position with the handle pointing BACKWARD, and test the same as for a simple locomotive.

0–4–0 *Type* (*Four-Wheel Switcher*).—A locomotive with four driving wheels having no front or trailing trucks. Used for switching cars in yards having curves of short radius.

0–6–0 *Type* (*Six-Wheel Switcher*).—A locomotive with three pair of driving wheels, but no front or trailing trucks. Used for shifting purposes.

0–8–0 *Type* (*Eight-Wheel Switcher*).—A locomotive with four pair of driving wheels, having no front or trailing trucks. Used for heavy switching service.

Geared Locomotive (*Not Classified in Whyte System*).—The geared locomotive is designed for service on steep grades and the entire weight of locomotive and tender is utilized for adhesion. A two or three cylinder vertical engine with Stephenson Valve Gear is mounted on one side just in front of the firebox, driving a horizontal shaft made in sections joined with flexible couplings that extends the entire length of locomotive and tender and drives all the wheels by means of bevel gears. The wheels are grouped in four-wheel swiveling trucks to enable the locomotive to round sharp curves.

REPRESENTATIVE TYPES.

The following matter contains descriptions and illustrations of the several prominent types of locomotives used for passenger and freight service, ending with a table of dimensions and characteristics of these and a number of other locomotives in general use throughout the United States.

In the passenger types, the most striking feature is their great boiler capacity. This has been obtained by providing large fireboxes with ample grate area, and an enormous amount of heating surface.

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In the usual construction the firebox is placed back of the driving wheels, either two or three pairs of large diameter, the resulting overhang carried on a pair of trailing wheels and the front end carried on a four-wheeled truck. This form allows the use of a large boiler, and a deep firebox as wide as roadway clearances will permit.

Great tractive effort and the great weight requisite for adhesion characterize the freight types. In order to obtain the maximum amount of the total weight of locomotive for adhesion two-wheeled leading trucks are usually used, and, until recently, the rest of the locomotive carried on the driving wheels, four or five pairs of small diameter, though recent designs of large dimensions provide trailing wheels at the back end for the overhang of the firebox, similar to the passenger types.

Southern Pacific 4–4–0.—The illustration of the Southern Pacific 4–4–0 type, Fig. 14, shows the general appearance of a representative locomotive of that type. It is of recent construction, designed for light or medium speed passenger service, and has the following general dimensions: Cylinders 20 inches × 26 inches, steam pressure 190 pounds, driving wheel diameter 73 inches, which develops a tractive effort of 23,008 pounds.

Lehigh Valley 4–4–2.—The illustration of the Lehigh Valley 4–4–2 type, Fig. 15, shows a locomotive having a Wootten firebox designed for burning anthracite coal. This locomotive has 20 inch × 26 inch cylinders, steam pressure of 200 pounds, driving wheels of 77 inches diameter, and develops a tractive effort of 22,961 pounds.

New York Central Lines 4–6–2.—The illustration of the New York Central Lines 4–6–2 type, Fig. 16, shows that company's standard locomotive for heavy fast passenger service, having a boiler equipped with a fire tube superheater. This locomotive has 23½ inch × 26 inch cylinders, steam pressure 200 pounds, driving wheels of 79 inch diameter, and develops a tractive effort of 30,898 pounds.

Santa Fe 4–6–2.—The illustration, Fig. 17, of the Atchison, Topeka and Santa Fe locomotive shows a balanced compound of the 4–6–2 type, designed for heavy passenger service in districts where the grades are heavy. The boiler of the locomotive illustrated has a Jacobs-Schupert firebox and a Buck-Jacobs superheater, in which the superheating chamber is built into the boiler shell.

Two steam domes are placed on these locomotives, the rear one being located back on the wagontop and the forward one being near the front end of the cylinder part of the boiler. Steam is conveyed from the rear dome to the forward dome through a pair of 5-inch internal pipes. The forward dome contains the throttle valve, which takes steam through the top only, and as communication between the boiler and front dome is closed by a plate, the steam supply is drawn

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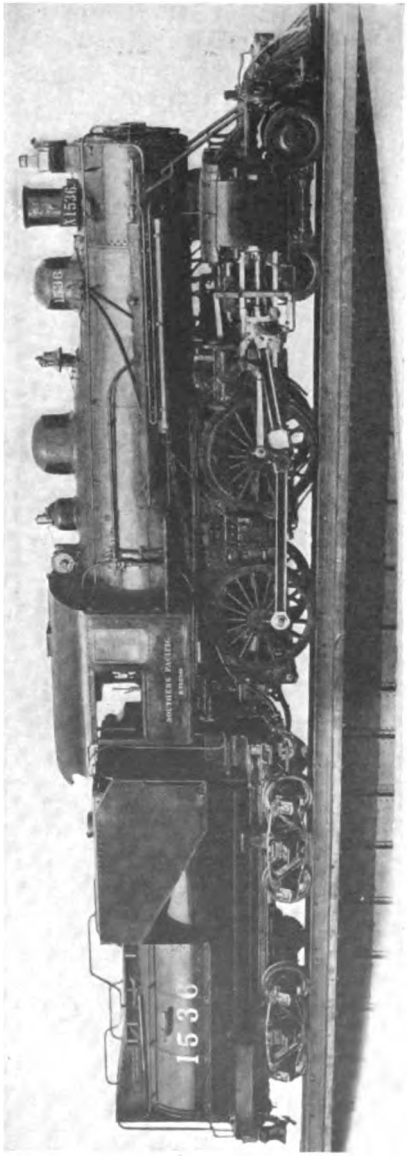

FIG. 14.—Passenger locomotive. 4-4-0 type (American).

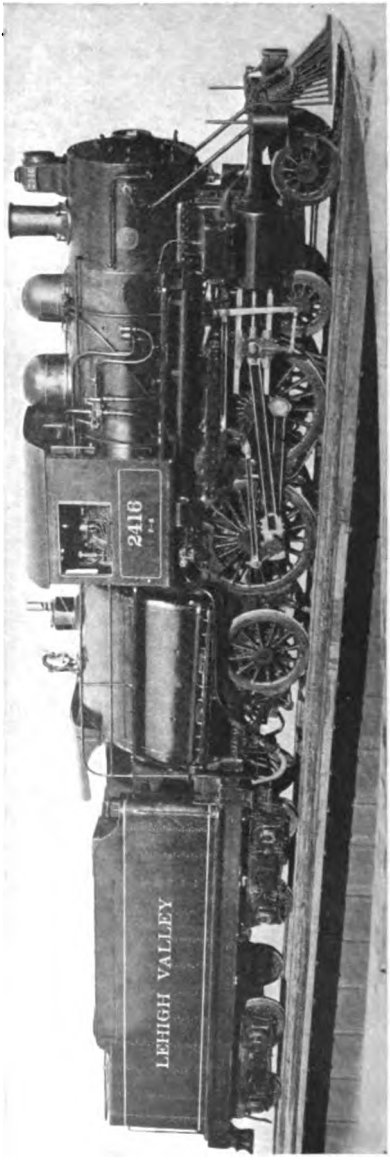

FIG. 15.—Passenger locomotive. 4-4-2 type (Atlantic).

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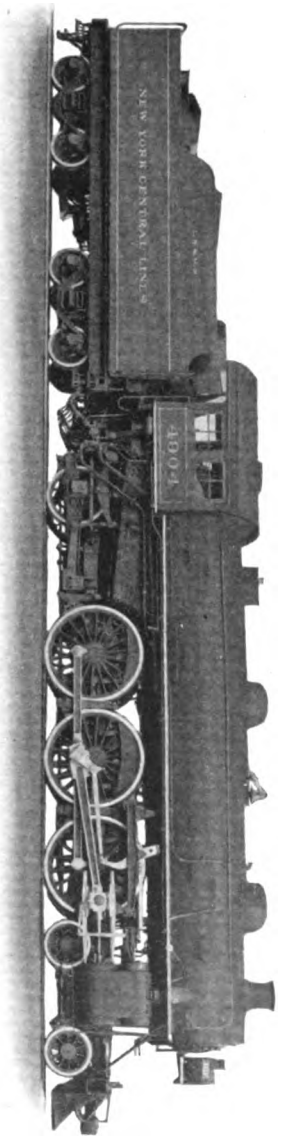

FIG. 16.—Passenger locomotive. 4-6-2 type (Pacific).

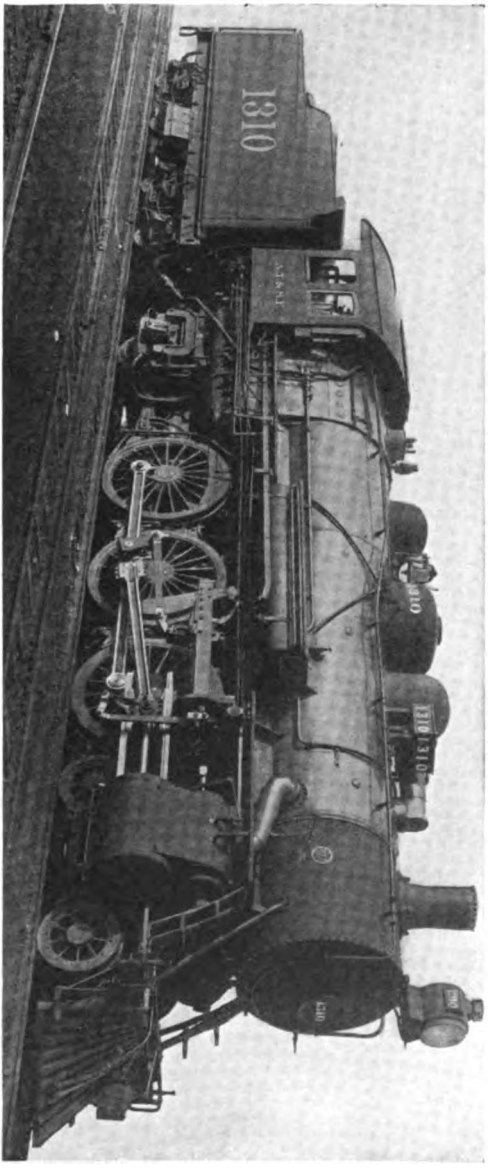

FIG. 17.—Passenger locomotive. 4-6-2 type (Pacific). Balanced compound (Baldwin).

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from the rear dome, which is at the highest part of the boiler, insuring dry steam.

The superheating chamber of the Buck-Jacobs superheater is 37 inches in length, its forward tube sheet being 24½ inches back of the center line of the smoke stack. An intermediate chamber is placed between the superheater and the evaporating section of the boiler and this chamber is accessible through a manhole so that the tubes at the front end of the boiler and at the back end of the superheater can be given necessary attention. In this type of superheater the steam enters on the top center line and is guided by internal baffle plates so that it follows a circuitous course among the tubes, and leaves the superheater through right and left steam pipes that connect directly with the steam chests.

This locomotive has 17½ inch and 29 inch × 28 inch cylinders, steam pressure of 210 pounds, driving wheels of 73 inch diameter, and develops 33,380 pounds tractive effort.

Chesapeake and Ohio 4–8–2.—The illustration of the Chesapeake and Ohio 4–8–2 type, Fig. 18, shows a new type of passenger locomotive designed for heavy passenger service on a mountain division of that railway having steep grades. It is equipped with a fire tube superheater, and also an overfeed mechanical stoker. This locomotive has the following dimensions: Cylinders 29 inch × 28 inch, steam pressure 180 pounds, driving wheels of 62 inch diameter, and develops a tractive effort of 58,110 pounds.

Pennsylvania Railroad 2–8–0.—The illustration of the Pennsylvania Railroad 2–8–0 type, Fig. 19, shows that company's standard freight locomotive. Among its distinguishing features are a Belpaire firebox, sufficient heating surface to make a speed of 20 miles an hour for long distances at practically full tractive effort and driving wheels of fairly large diameter that enable the locomotive to attain moderately high speed.

A locomotive of this type hauled a train of 105 cars from Altoona, Pa., to Enola, Pa., a division of 127 miles with maximum grades of 12 feet to the mile, in seven hours and twelve minutes, or at an average speed of 17.6 miles per hour. The total weight of this train, including engine, tender and caboose, was 7644 tons, and the weight of lading, coal, was 5544 tons. The train was about 3600 feet long.

This locomotive has 24 inch × 28 inch cylinders, 205 pounds steam pressure, 62 inch driving wheels, and develops a tractive effort, calculated according to tractive effort formula for simple locomotives given in Part I of 45,327 pounds.

Great Northern 2–8–2.—The illustration of the Great Northern 2–8–2 type, Fig. 20, shows a locomotive designed for moderately high speed heavy freight service. This locomotive also has Belpaire type

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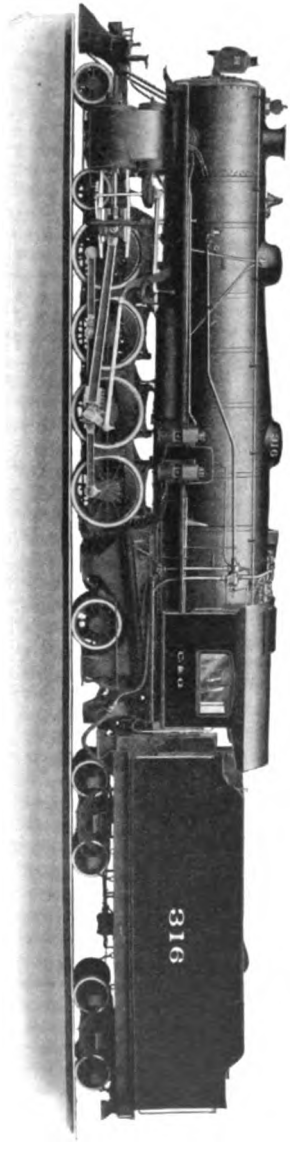

FIG. 18.—Passenger locomotive. 4–8–2 type (Mountain).

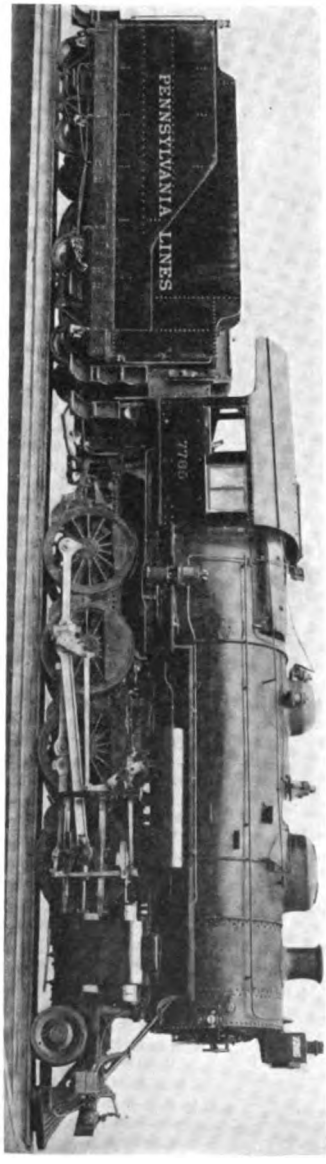

FIG. 19.—Freight locomotive. 2–8–0 type (Consolidation).

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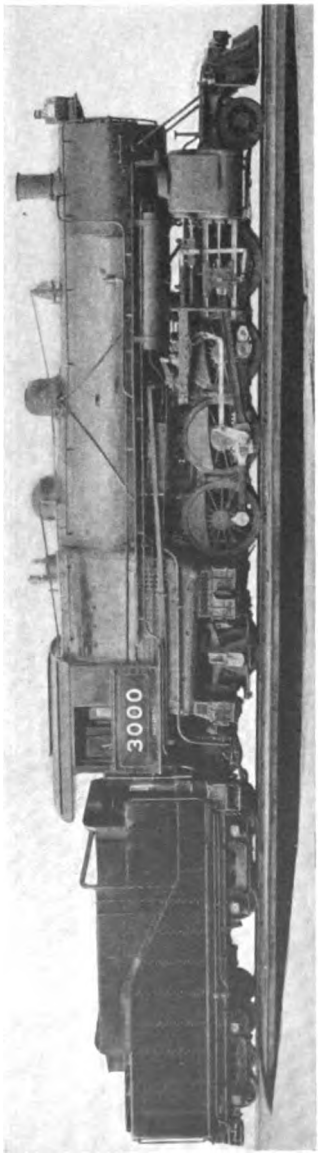

FIG. 20.—Freight locomotive. 2–8–2 type (Mikado).

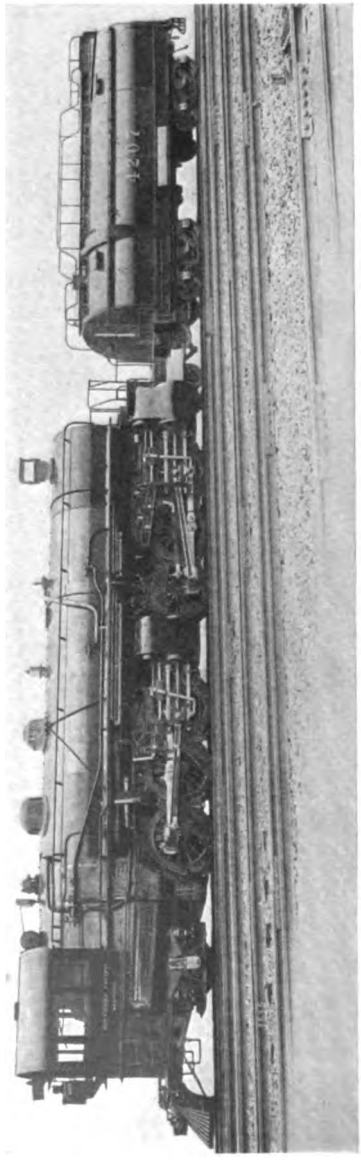

FIG. 21.—Passenger locomotive. 2–6–6–2 type (Mallet articulated compound).

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firebox and its boiler is fitted with a fire tube superheater having 1060 square feet of heating surface, which delivers high degree superheated steam to the cylinders. The boiler pressure is only 170 pounds, and in order to obtain the requisite tractive effort very large cylinders are applied. The cylinders are 28 inch × 32 inch, and the driving wheels are 63 inch diameter, which gives the locomotive a tractive effort of 57,543 pounds.

Southern Pacific 2–6–6–2.—The illustration of the Southern Pacific Mallet articulated 2–6–6–2 compound type, Fig. 21, shows a locomotive designed for passenger service, several being used in that service on the Sacramento division. On these locomotives the Baldwin Separable type of boiler is applied, the firebox section being the boiler proper and the section adjacent to the smoke box being a feed-water heater.

A peculiarity of these locomotives is that they are designed to run firebox end first, which gives the engine crew an unobstructed view of the track ahead. This is permissible with these particular locomotives, as they burn oil and the tender does not have to be adjacent to the firebox.

The tractive effort exerted by them is 66,666 pounds, and they haul a passenger train of 500 tons at schedule speed over the Sacramento division, having a continuous ascending grade, eastbound Sacramento to Summit, 105 miles, with a total rise of 7000 feet, and a maximum grade of 116 feet per mile for about 40 miles, where two locomotives of the 4–6–0 type were formerly required. Their cylinders are 25 inch and 38 inch × 28 inch, steam pressure 200 pounds, and the diameter of driving wheels 63 inches.

New York Central Lines 2–6–6–2.—The illustration of the New York Central Mallet articulated 2–6–6–2 compound type, Fig. 22, shows a locomotive designed for heavy slow freight service on the Pennsylvania division of the New York Central lines.

Twenty-six locomotives of this type are handling the traffic on this division which previously required 60 locomotives of the 2–8–0 type, having a tractive effort of 45,700 pounds. A single Mallet hauls a 4000-ton train over the division without assistance, while previously the maximum tonnage of the 2–8–0 type was 3500 tons and helpers were required to assist on the heavier grades. The Mallet type has shown a saving of 35 per cent. on fuel per ton mile, and the operating capacity of the division has been increased over 40 per cent.

These locomotives are equipped with a fire tube superheater and a brick arch. The American Locomotive Company's system of compounding, which requires an intercepting valve, is present. This system of compounding makes it possible to secure 20 per cent. increase of power when using steam direct from the boiler in both the

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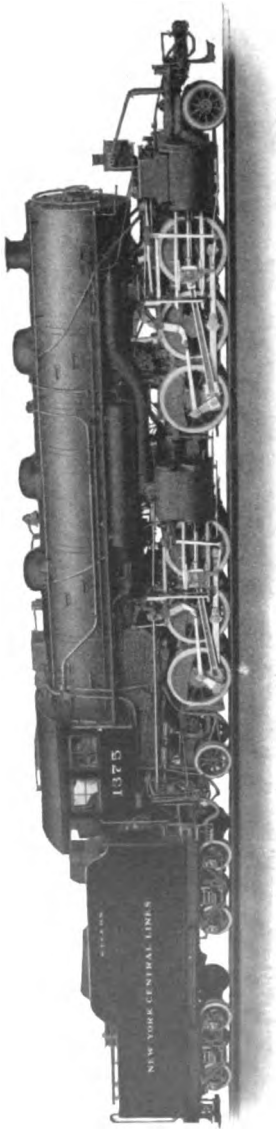

FIG. 22.—Freight locomotive. 2-6-6-2 type (Mallet articulated compound).

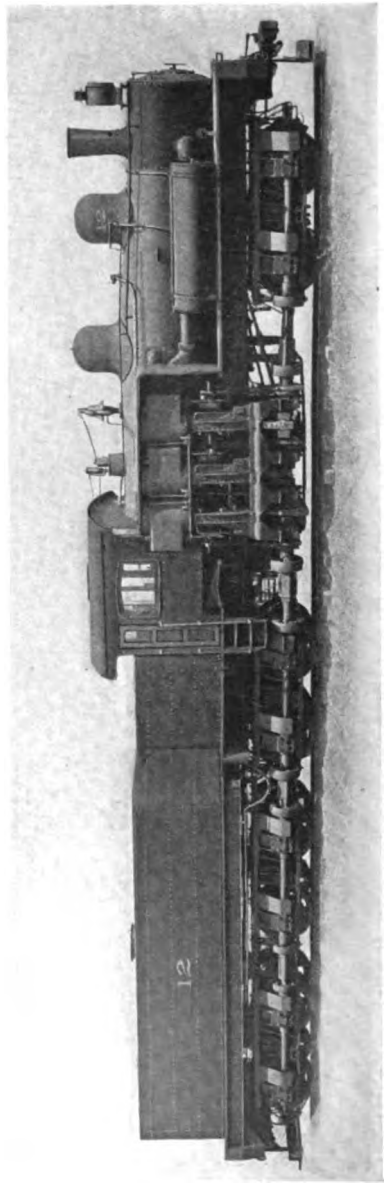

FIG. 23.—Shay geared locomotive. Class B.

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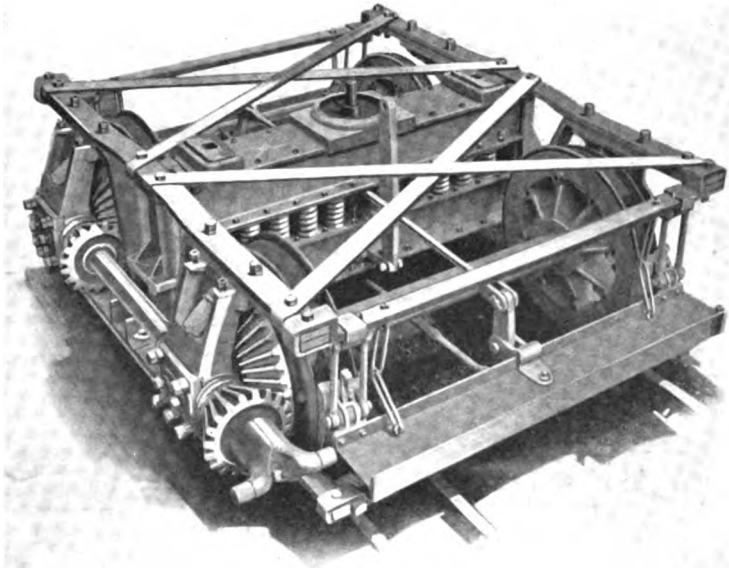
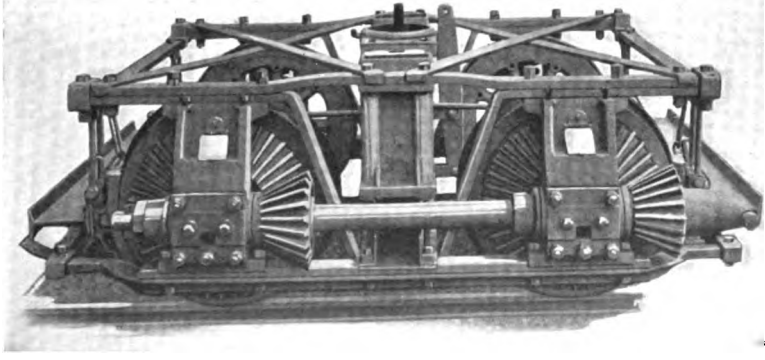


END VIEW.



SIDE VIEW.

FIG. 24.—Shay geared locomotive trucks.

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high and low pressure cylinders, or operating simple. In a test, in order to determine the advantages of this system, a train of 63 steel cars and a caboose, having a total weight of 4465 tons behind the tender, was hauled over the division by one locomotive without stalling.

These locomotives have the following dimensions and characteristics: Cylinders 21½ inch and 34 inch × 32 inch, steam pressure 200 pounds, driving wheel diameter of 57 inches, and develop a tractive effort, working compound, of 67,500 pounds.

Shay Geared Locomotive.—The accompanying illustration, Fig. 23, shows a geared locomotive of the Shay type, built by the Lima Locomotive and Machine Company, and classed by them as Class "B," and also end and side views of the trucks of this type of locomotive, Fig. 24. The following tables give the principal dimensions, characteristics and hauling capacity of a Shay Class "D" locomotive, similar to the illustration, built for the Chesapeake and Ohio Railroad.

Boiler Pressure Lbs.	Cylinders			Wheel Base		Drivers		Tractive Effort	Weight in Working Order	Capacity of Tank for Water	Fuel Capacity of Coal
	No.	Diam.	Stroke	Rigid	Total	No.	Diam.				
		In.	In.	In.	Ft. In.		In.	Lbs.	Tons	Gallons	Tons
200	3	17	18	64	58 4	16	46	53000	150	8000	9

HAULING CAPACITY IN TONS OF 2,000 LBS. (Exclusive Engine and Tender.)

On Level	On Grades						
	½ Per cent.	1 Per cent.	2 Per cent.	3 Per cent.	4 Per cent.	5 Per cent.	6 Per cent.
6475	2792	1743	954	629	452	341	264

In the table of dimensions and characteristics following, the item Tractive Effort × Diameter Drivers ÷ Total Heating Surface states the rule usually employed for estimating the steaming capabilities of a locomotive. This phrase suggests the relation existing between the power of the locomotive and its heating surface, for the product of Tractive Effort × Diameter Drivers, termed "cylinder duty factor," is proportional to the foot pounds of work done in the cylinders in each revolution of the driving wheels, and so dividing this product by the heating surface the quotient is proportional to the work done per square foot of heating surface during each revolution. This result is usually termed the "steaming capacity factor," sometimes referred to as the "B. D." factor (boiler duty factor), and the lower the value of the B. D. factor the better the steaming qualities of the locomotive.

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TABLES OF DIMENSIONS AND CHARACTERISTICS.

Name of road	C.R.R. of N.J.	S.P.	P.R.R.
Builder	A.L. Co.	Bald.	P.R.R.
When built	1905	.....	....
Class	4-4-0	4-4-0	4-4-2
Simple or compound	Simple	Simple	Simple
Cylinders, number	2	2	2
Valve gear, type	Steph.	Wals.	Wals.
Cylinders, diameter	19″	20″	22″
Cylinders, stroke	26″	26″	26″
Steam pressure, lbs	200	190	205
Diameter of drivers	69″	73″	80″
Tractive effort, lbs	23124	23008	27409
Boiler, type	Wootten	W.T.	Belpaire
Boiler, smallest diameter	62¼″	65″	65⅝″
Firebox, length	122⅛″	108″	111″
Firebox, width	96¼″	37¼″	72″
Grate area, sq. ft	81.6	28	55.5
Fuel, kind	Anth. Coal.	Oil.	Bit. Coal
Tubes, number, fire tube	280	330	315
Tubes, number, superheater	.....	.....	.....
Tubes, diameter, fire tube	2″	2″	2″
Tubes, diameter, superheater	.....	.....	.....
Tubes, length	12′ 6″	12′ 8″	15′
Heating surface, tubes, sq. ft	1838.1	2174	2474
Heating surface, firebox, sq. ft	167.6	176	166
Heating surface, total, sq. ft	2005.7	2350	2640
Heating surface, superheater, sq. ft.	.....	.....	.....
T. E. × diam. drivers ÷ total H. S.	795	715	830
Total heating surface ÷ grate area	24.5	83.9	47.5
Weight, total, lbs	161300	146000	188600
Weight on drivers, lbs	111300	100000	124100
Weight on leading truck, lbs	50000	46000	33200
Weight on trailer, lbs	.....	.....	31300
Weight, tender, loaded, lbs	122200	138000	132500
Tender, coal capacity, tons	12	2940 gals.	12.5
Tender, water capacity, gals	5000	7000	5500

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TABLES OF DIMENSIONS AND CHARACTERISTICS.—*Continued.*

Name of road	L. V.	G. N.	D. L. & W.
Builder	Bald.	Bald.	A. L. Co.
When built	.....	.....	1905
Class	4-4-2	4-6-0	4-6-0
Simple or compound	Simple	Simple	Simple
Cylinders, number	2	2	2
Valve gear, type	Wals.	Wals.	Steph.
Cylinders, diameter	20″	26″	21½″
Cylinders, stroke	26″	30″	26″
Steam pressure, lbs	200	150	215
Diameter of drivers	77″	73″	69″
Tractive effort, lbs	22961	35420	31831
Boiler, type	Wootten	Belpaire	Wootten
Boiler, smallest diameter	66″	72″	74⅝″
Firebox, length	108⅜″	108″	126⅛″
Firebox, width	102⅜″	66¼″	108¼″
Grate area, sq. ft	76.9	50	94.8
Fuel, kind	Anth. Coal	Bit. Coal	Anth. Coal
Tubes, number, fire tube	320	180	398
Tubes, number, superheater	.....	26	.....
Tubes, diameter, fire tube	2″	2¼″	2″
Tubes, diameter, superheater	.....	5″	.....
Tubes, length	16′ 2⅞″	16′ 6″	15′ 3″
Heating surface, tubes, sq. ft	2705	2296	3156
Heating surface, firebox, sq. ft	178	156	222
Heating surface, total, sq. ft	2883	2452	3378
Heating surface, superheater, sq. ft.	.....	440	.....
T. E. × diam. drivers ÷ total H. S.	613	830*	650
Total heating surface ÷ grate area	37.5	62.2*	35.6
Weight, total, lbs	184650	200000	201000
Weight on drivers, lbs	107250	150000	154000
Weight on leading truck, lbs	40200	50000	47000
Weight on trailer, lbs	35200	.....	.....
Weight, tender, loaded, lbs	135350	150000	120000
Tender, coal capacity, tons	12	13	10
Tender, water capacity, gals	7000	8000	6000

* Total heating surface includes superheater heating surface, computed on a basis of one sq. ft. of superheater heating surface equalling one and one-half sq. ft. of fire tube heating surface.

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TABLES OF DIMENSIONS AND CHARACTERISTICS.—*Continued.*

Name of road	P. R. R.	N. Y. C. Lines	C. B. Q.
Builder	P. R. R.	A. L. Co.	Bald.
When built	.....	.....	.....
Class	4-6-2	4-6-2	4-6-2
Simple or compound	Simple	Simple	Simple
Cylinders, number	2	2	2
Valve gear, type	Wals.	Wals.	Wals.
Cylinders, diameter	24″	23½″	25″
Cylinders, stroke	26″	26″	28″
Steam pressure, lbs	205	200	160
Diameter of drivers	80″	79″	69″
Tractive effort, lbs	32619	30898	34492
Boiler, type	Belpaire	Rad. Stay	Rad. Stay
Boiler, smallest diameter	78″	72″	70″
Firebox, length	110¾″	108⅛″	108⅛″
Firebox, width	72″	75¼″	72¼″
Grate area, sq. ft.	55.4	56.5	55
Fuel, kind	Bit. Coal	Bit. Coal	Bit. Coal
Tubes, number, fire tube	359	175	170
Tubes, number, superheater	.....	32	24
Tubes, diameter, fire tube	2¼″	2¼″	2¼″
Tubes, diameter, superheater	.....	5½″	5½″
Tubes, length	20′ 10¹³⁄₁₆″	21′ 6″	21′
Heating surface, tubes, sq. ft.	4421	3192.9	2816
Heating surface, firebox, sq. ft.	199	231.2†	194
Heating surface, total, sq. ft.	4620	3424.1	3010
Heating surface, superheater, sq. ft.	.....	765	925
T. E. × diam. drivers ÷ total H. S.	565	534*	541*
Total heating surface ÷ grate area	83.3	81*	80*
Weight, total, lbs	272000	269000	236100
Weight on drivers, lbs	178500	171500	153100
Weight on leading truck, lbs.	47500	50000	43950
Weight on trailer, lbs.	46000	47500	39050
Weight, tender, loaded, lbs.	158000	155200	158900
Tender, coal capacity, tons	13	12	13
Tender, water capacity, gals	7000	7500	8200

* Total heating surface includes superheater heating surface, computed on a basis of one sq. ft. of superheater heating surface equalling one and one-half sq. ft. of fire tube heating surface.

† Includes 27.1 sq. ft. of water tube (arch pipe) heating surface.

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TABLES OF DIMENSIONS AND CHARACTERISTICS.—*Continued.*

Name of road	A. T. & S. F.	C. & O.	P. R. R.
Builder	Bald.	A. L. Co.	P. R. R.
When built	1912	1911	.....
Class	4-6-2	4-8-2	2-8-0
Simple or compound	Compound	Simple	Simple
Cylinders, number	4	2	2
Valve gear, type	Wals.	Wals.	Wals.
Cylinders, diameter	17½" & 29"	29"	24"
Cylinders, stroke	28"	28"	28"
Steam pressure, lbs	210	180	205
Diameter of drivers	73"	62"	62"
Tractive effort, lbs	33380	58110	45327
Boiler, type	Jacobs-Schupert	Rad. Stay.	Belpaire
Boiler, smallest diameter	70"	83¾"	76¾"
Firebox, length	109⅝"	114⅛"	110¼"
Firebox, width	75¾"	84¼"	72"
Grate area, sq. ft	57.6	66.7	55.1
Fuel, kind	Bit. Coal.	Bit. Coal	Bit. Coal
Tubes, number, fire tube	290	243	465
Tubes, number, superheater	.....	40	.....
Tubes, diameter, fire tube	2¼"	2¼"	2"
Tubes, diameter, superheater	.....	5½"	.....
Tubes, length	18'2"	.19'‡	15'
Heating surface, tubes, sq. ft	3088	3897	3652
Heating surface, firebox, sq. ft	237	337	187
Heating surface, total, sq. ft	3325	4234	3839
Heating surface, superheater, sq. ft.	806†	845	.....
T. E. × diam. drivers ÷ total H. S.	537†	654*	732
Total heating surface ÷ grate area	78.7†	82.4*	69.6
Weight, total, lbs	276500	330000	238300
Weight on drivers, lbs	160900	239000	211000
Weight on leading truck, lbs	54980	44000	27300
Weight on trailer, lbs	60620	47000	.....
Weight, tender, loaded, lbs	171500	173400	154000
Tender, coal capacity, tons	12	15	17.5
Tender, water capacity, gals	9000	9000	7000

* Total heating surface includes superheater heating surface, computed on a basis of one sq. ft. of superheater heating surface equalling one and one-half sq. ft. of fire tube heating surface.

† This locomotive is equipped with a Buck-Jacobs superheater in the front end of the boiler, making virtually a front section of the same. It contains 350 2¼" and 67-3" tubes and one (1) 6" tube, all about 37 inches in length.

‡ This locomotive's boiler contains a combustion chamber.

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TABLES OF DIMENSIONS AND CHARACTERISTICS.—*Continued.*

Name of road	C. & N. W.	G. N.	C. M. & St. P.
Builder	A. L. Co.	Bald.	R. R. Co.
When built	.....	1911	1909
Class	2-8-0	2-8-2	2-8-2
Simple or compound	Simple	Simple	Simple
Cylinders, number	2	2	2
Valve gear, type	Wals.	Wals.	Wals.
Cylinders, diameter	25″	28″	24″
Cylinders, stroke	32″	32″	30″
Steam pressure, lbs	170	170	200
Diameter of drivers	61″	63″	63″
Tractive effort, lbs	47377	57543	46627
Boiler, type	Rad. Stay.	Belpaire	Rad. Stay
Boiler, smallest diameter	81½″	82″	73¾″
Firebox, length	108¼″	117″	107″
Firebox, width	70¼″	96″	65¾″
Grate area, sq. ft	52.7	78.2	48.8
Fuel kind	Bit. Coal	Bit. Coal	Bit. Coal
Tubes, number, fire tube	443	326	366
Tubes, number, superheater	.....	30	.....
Tubes, diameter, fire tube	2″	2″	2″
Tubes, diameter, superheater	.....	5½″	.....
Tubes, length	15′ 2″	21′	17′ 6″
Heating surface, tubes, sq. ft	3499	4471	3332
Heating surface, firebox, sq. ft	214	249	282
Heating surface, total, sq. ft	3713	4720	3614
Heating surface, superheater, sq. ft.	.....	1060	.....
T. E. × diam. drivers ÷ total H. S.	778	574*	812
Total heating surface ÷ grate area	70.4	80.6*	74
Weight, total, lbs	232000	287000	260500
Weight on drivers, lbs	205000	220000	201000
Weight on leading truck, lbs	27000	27000	25000
Weight on trailer, lbs	.....	40000	34500
Weight, tender, loaded, lbs	150900	148000	154000
Tender, coal capacity, tons	12	13	14
Tender, water capacity, gals	7500	8000	8000

*Total heating surface includes superheater heating surface, computed on a basis of one sq. ft. of superheater heating surface equalling one and one-half sq. ft. of fire tube heating surface.

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TABLES OF DIMENSIONS AND CHARACTERISTICS.—*Continued.*

Name of road	D. & H.	N. P.	G. N.
Builder	A. L. Co.	Bald.	Bald.
When built	1910	1907	.....
Class	0-8-8-0	2-6-6-2	2-6-6-2
Simple or compound	Compound	Compound	Compound
Cylinders, number	4	4	4
Valve gear, type	Wals.	Wals.	Wals.
Cylinders, diameter	26" & 41"	21½" & 33"	20" & 31"
Cylinders, stroke	28"	32"	30"
Steam pressure, lbs	220	200	210
Diameter of drivers	51"	55"	55"
Tractive effort, lbs	105000	64547‡	54989‡
Boiler, type	Rad. Stay	Belpaire	Belpaire
Boiler, smallest diameter	90"	84"	72"
Firebox, length	126⅛"	117"	116⅛"
Firebox, width	114"	96"	66¼"
Grate area, sq. ft	100	78	53.4
Fuel, kind	.....	Bit. Coal	Bit. Coal
Tubes, number, fire tube	446	437	301
Tubes, number, superheater	.....	.....	.....
Tubes, diameter, fire tube	2¼"	2¼"	2¼"
Tubes, diameter, superheater	.....	.....	.....
Tubes, length	24'	21'	21'
Heating surface, tubes, sq. ft	6276	5383	3708
Heating surface, firebox, sq. ft	353	225	198
Heating surface, total, sq. ft	6629	5608	3906
Heating surface, superheater, sq. ft.	.....	.....	.....
T. E. × diam. drivers ÷ total H. S.	807	633	774
Total heating surface ÷ grate area	66.3	71.8	73
Weight, total, lbs	445000	351600	302650
Weight on drivers, lbs	445000	313550	263350
Weight on leading truck, lbs	.....	18450	17900
Weight on trailer, lbs	.....	19600	21400
Weight, tender, loaded, lbs	166800	148400	147350
Tender, coal capacity, tons	14	13	13
Tender, water capacity, gals	9000	8000	8000

‡ Tractive effort calculated according to Baldwin Locomotive Works formula.

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TABLES OF DIMENSIONS AND CHARACTERISTICS.—*Concluded.*

Name of road	S. P.	N. Y. C. Lines
Builder	Bald.	A. L. Co.
When built	1911	.....
Class	2-6-6-2	2-6-6-2
Simple or compound	Compound	Compound
Cylinders, number	4	4
Valve gear, type	Wals.	Wals.
Cylinders, diameter	25" & 38"	21½" & 34"
Cylinders, stroke	28"	32"
Steam pressure, lbs	200	200
Diameter of drivers	63"	57"
Tractive effort, lbs	66666†	67500
Boiler, type	Rad. Stay	Rad. Stay
Boiler, smallest diameter	82"	83¾"
Firebox, length	120⅝"	108⅛"
Firebox, width	84"	75¼"
Grate area, sq. ft	70	56.5
Fuel, kind	Oil	Bit. Coal
Tubes, number, fire tube	495	235
Tubes, number, superheater	.....	36
Tubes, diameter, fire tube	2"	2¼"
Tubes, diameter, superheater	.....	5½"
Tubes, length	20' 6"	22'
Heating surface, tubes, sq. ft	6882†	4168
Heating surface, firebox, sq. ft	235	225
Heating surface, total, sq. ft	7117	4393
Heating surface, superheater, sq. ft	.....	966
T. E. × diam. drivers ÷ total H. S.	590	658*
Total heating surface ÷ grate area	101.6	103*
Weight, total, lbs	384800	354000
Weight on drivers, lbs	320100	301500
Weight on leading truck, lbs	21000	26000
Weight on trailer, lbs	43700	26500
Weight, tender, loaded, lbs	183200	153700
Tender, coal capacity, tons	3200 gals.	12
Tender, water capacity, gals	10000	8000

*Total heating surface includes superheater heating surface, computed on a basis of one sq. ft. of superheater heating surface equalling one and one half sq. ft. of fire tube heating surface.
†Includes feed-water heating surface.

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PART III

USEFUL NOTES AND TABLES

PHYSICS, MECHANICS—DYNAMICS, HEAT, CHEMISTRY, COAL, COMPOSITION, HEAT VALUES, AND WEIGHTS OF FUELS, TABLES.

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PHYSICS.

THE two terms *physics* and *chemistry* can best be defined by stating that physics deals with physical change, whereas chemistry relates to chemical change. The freezing of water and the melting of ice are common physical changes, while combustion of fuel substances is a well known chemical change.

In presenting a definition of physics it is unnecessary to discuss the objective reality or non-reality of the universe, nor express an opinion regarding the nature of life, as these matters are purely metaphysical. Therefore, we assume that the physical universe has a true existence; that all occurring processes evolve according to some natural law, and that there are but two classes of things that sustain this physical universe—*matter* and *energy*.

Matter is everything that occupies space. It exists in *masses, molecules,* and *atoms*. The last two named divisions are invisible, though determinable quantities.

A molecule usually consists of two or more atoms. The atom may be composed of still smaller particles, termed *electrons,* for the opinion now obtains that the basis of all matter is one thing, and that this smallest, ultimate unit of matter is electrical energy; but for the purposes of this book this is not important, and we need go no further than molecules and atoms.

There are many kinds of matter, and they differ from one another in their various physical properties. Two or more kinds can unite so as to produce matter (compounds) that differs entirely, it may be, from its constituents in physical properties and characteristics, but no combination or change of properties in matter can occur without involving some external influence.

Matter exists in three states or conditions: Solid, liquid or gaseous.

A solid body is one whose molecules change their relative positions with great difficulty; the molecules of liquid bodies change their relative positions easily; in gaseous bodies the molecules tend to separate from one another.

Molecules are combinations of atoms that are held to one another by the same force of universal attraction that holds the earth, moon, sun and stars in their relative positions, and they revolve about each other at distances controlled by the relation of their force of attraction and the centrifugal force of circular motion. These molecules are separated by distances many times their own diameters, and they swing around each other at great velocities. If their attractive force is greater than their centrifugal force the molecules are held in fixed paths and the body remains solid. When matter is heated energy is imparted to these whirling molecules that causes their momentum (velocity) to

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increase, and they swing in wider circles or ellipses, resulting in the body expanding. With continued application of heat—*i.e.,* increasing the velocity of the molecules, the centrifugal force becomes stronger and the attractive force weaker until the body finally changes form. When heat is absorbed or withdrawn from the body the opposite of this condition is effected and contraction takes place.

Matter is said to possess *inertia*—that is, a material body can do nothing of itself. If at rest, it cannot move unless something outside of itself sets it in motion, and if in motion, it cannot come to rest or change its motion, course, or velocity unless acted upon by something external to it. When matter is set in motion or its motion altered either by direct collision or influence of some other portion of matter, it is commonly said that the second body "does work" on the first, or that the first has work done on it by the second.

Energy is the ability to do work either in producing, destroying or changing motion of matter in opposition to a resisting force. Energy is of two kinds, *kinetic* or *potential.* The energy due to the motion of a body is kinetic or actual energy. The energy a body may possess due to advantage of position is called potential energy.

A car standing on an incline with the brake applied does no work, but if the brake were released the car would move down the incline and do work. This ability to do work is owing to its advantage of position—*i.e.,* it possesses stored-up or potential energy.

Energy in one form may be transformed into energy of another form. There is stored in coal a certain amount of potential energy that is transformed into kinetic energy in the form of heat when the coal is burned. The kinetic energy of heat changes water to steam, giving it potential energy, and this in turn acting in the cylinder of an engine enables it to overcome a resisting force, or the potential energy of steam is changed to kinetic and performs useful work.

Matter and energy must always have existed, and they never can be annihilated, destroyed, or lost. Matter is essentially passive, changing its properties only when influenced, while energy is constantly in state of change. This property of transformation is energy's distinguishing characteristic. It may be transformed from one body to another; or it may disappear at one place and reappear at some other; but no matter what transformation takes place, when the total effects of the exertion of a given amount of energy are summed up the result must and will be precisely equal to the original amount expended. Consequently, the sum total of energy, and also matter, is unalterable and must forever remain so.

MECHANICS—DYNAMICS.

Dynamics is that branch of physics that treats of forces and their effects, while mechanics relates to the adapting of machines and contrivances by which these forces can be utilized most advantageously.

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Force.—Force is anything that produces, destroys or changes the direction of motion. If a body is at rest, anything that tends to put it in motion is a force; if a body is in motion, anything that tends to change either its direction or its rate of motion is a force. With the existence of every force there is a *reaction,* a simultaneous equal and opposing force.

Force may be divided into two classes, *extraneous* and *molecular:* extraneous forces act on bodies from without; molecular forces are exerted between the neighboring particles of bodies.

Extraneous forces are of two kinds, pressures and moving forces: pressures simply tend to produce motion, moving forces actually produce it.

Molecular forces are also of two kinds, attractive and repellent: attractive forces tend to bind the particles of a body together; repellent forces tend to thrust them asunder. Both kinds of molecular forces are continually exerted between the molecules of bodies, and on the one or the other depends the physical state of a body, as solid, liquid, or gaseous. The *unit* of *force,* ordinarily used in engineering, is the pound avoirdupois.

Inertia.—Inertia (inertness) is that property of a body by virtue of which it tends to continue in a state of rest or in motion until acted on by some force—*i.e.,* the inability of matter to set itself in motion, or if in motion to change the rate or direction of motion.

Motion.—Motion is a change of position in relation to some object that for purpose of comparison is regarded as being fixed.

Velocity.—Velocity is rate of motion. It is expressed by units of space passed over in units of time. When equal spaces are passed over in equal units of time the velocity is said to be *uniform,* and when the spaces passed over are unequal in equal units of time the velocity is said to be *variable.*

The unit of space ordinarily used is the foot.

Momentum.—The momentum of a body is its quantity of motion. It is the product obtained by multiplying the mass of a moving body by its velocity in feet per second.

NOTE.—A mass is any quantity of matter that is composed of molecules. Size is a measure of mass between bodies of the same material, but not between bodies of different materials.

Work.—Work is done when a body is moved against or in opposition to a force tending to prevent such movement. Resistance and space are essential elements of work. When a train is moved, work is done in overcoming the force of friction that exists between the wheels and the rails. When the work performed in moving a train is considered, it may be seen that motion is an essential element. As there are many kinds of work it is necessary to have a common unit of measurement to express the amount of work performed. A unit of resistance is combined with a unit of space to form a unit of work.

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The unit of resistance being a pound and the unit of space a foot, the unit of work is called a *foot-pound*. A foot-pound is the amount of work necessary to move a body a distance of one foot in any direction against a resistance of one pound.

Power.—Power is the rate of doing work or the amount of work done in a unit of time, as foot-pounds per second, etc. The unit of power in common usage is the *horse power*, which was established on the basis of a strong draught-horse's capacity for doing work during a short period of time. This unit is 33,000 foot-pounds per minute, 550 foot-pounds per second, 1,980,000 foot-pounds per hour.

Center of Gravity.—The center of gravity of a body, or a system of bodies rigidly connected, is the point about which, if suspended, all the parts will be in equilibrium—that is, there will be no tendency to rotate. In bodies of equal heaviness throughout, the center of gravity is the center of magnitude.

If a body be suspended at its center of gravity, it will be in equilibrium in all positions. But if suspended at a point out of its center of gravity, it will swing into such a position that its center of gravity is vertically beneath its point of suspension.

Efficiency.—The efficiency of a machine is a fraction expressing the ratio of useful work to the whole work performed, which is equal to the energy expended. The limit to the efficiency of a machine is unity, denoting the efficiency of a perfect machine in which no work is lost.

The difference between the energy expended and the useful work done, or the loss, is usually expended either in overcoming friction or in doing work on bodies surrounding the machine from which no useful work is received. Thus, in a locomotive pulling a train, part of the energy exerted in the cylinder does useful work of giving motion to the locomotive and train, and the remainder is spent in overcoming the friction of the machinery, of the journal bearings and the rolling friction of the wheels on the rail.

Friction.—Friction is the property that tends to resist relative motion between two bodies in sliding or rolling contact—*i.e.*, motion of one of the bodies relatively to the other; for when one body rests upon another the projections and depressions of the surfaces in contact (since no surface can be made absolutely smooth) interlock to a greater or less extent, and in order to slide one over the other some force must be expended either in separating the bodies (as by lifting the upper one) sufficiently to clear the projections or in breaking them off. The amount of resistance due to friction between metals in sliding contact is proportional to the pressure, independently of the area of the surface, though it usually varies with different metals.

The *co-efficient* of friction is the ratio of force required to slide a body along a horizontal plane surface to the weight of the body. Thus, in Fig. 25, if the force of 10 pounds just balances the resistance

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due to friction between the weight W, of 50 pounds, and the plane surface P, then the co-efficient of friction between

$$W \text{ and } P = \frac{10 \text{ pounds}}{50 \text{ pounds}} = 0.2 \text{ pound.}$$

The co-efficient of friction is usually expressed decimally or by a common fraction, except an equivalent application to locomotives, cars or trains moving on tracks, which is expressed in pounds per ton.

FIG. 25.—Diagram illustrating co-efficient of friction.

Pressure.—The term pressure used in connection with steam, or air, means the force exerted against the surface of containing vessel, and is usually expressed in pounds per square inch.

NOTE.—The steam gauge indicates pressure above atmospheric only—*i.e.,* the gauge pointer does not leave the zero mark and indicate pressure until the steam pressure in the boiler becomes greater than the pressure of the atmosphere, or the actual steam pressure in the boiler is gauge-pressure plus atmospheric, and the sum of these two pressures is termed *absolute pressure,* and, therefore, absolute pressure is reckoned from a perfect vacuum. In making calculations involving steam pressure (and air pressure, too) absolute pressure should always be used, and, if necessary, subtract atmospheric to get final result.

Volume.—The word volume is a relative term used in engineering calculations involving expansion (or compression) of steam or air. In making such calculations the same unit of measurement is arbitrarily assigned to each quantity. For example: Suppose steam is admitted at boiler pressure to the cylinder of an engine while the piston makes one-quarter stroke and the supply then cut off, allowing it to expand till the piston reaches the end of the stroke. Then this quantity of steam from the boiler, which was one-quarter cylinder full, expands, fills the cylinder, becomes a quantity four times as great as the original, and would be referred to as one volume of steam expanding to four volumes.

HEAT.

Heat.—Heat is a form of energy of measurable quantity, though not of material substance. It and mechanical work are mutually convertible. In the cylinder of a steam engine heat disappears and work appears as a result. On the other hand, work is expended in

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overcoming the friction of a bearing and heating of the bearing results.

Temperature.—Temperature is a term used to indicate how hot or cold a body is. In this connection it should be remembered that cold is not a form of energy; that when matter receives heat either its temperature rises or its physical condition changes, and that when this matter gives up heat either its physical condition reverts to the original or its temperature lowers, becomes cold. Therefore the sensation of cold is absence of heat.

The distinction between heat and temperature becomes clearer by considering the meaning of the words hot and cold as applied to different material substances. Two bodies may really be of the same temperature, and yet to the sense of touch one may apparently feel hot, the other cold. Thus a mass of iron and a mass of wood may be of equal temperatures, though feel different to the touch. If the temperature of the hand be higher than the two, the iron will feel cold and the wood feel warm; while if the temperature of the hand be lower than that of the bodies, these conditions will be reversed. The reason is that the physical properties of these substances differ greatly, the iron having good heat conducting properties rapidly abstracts from, or supplies heat to, the hand.

Sensible Temperature.—Sensible temperature is the degree of heat apparent, measurable by thermometers and heat indicating instruments, though not necessarily quantitative.

Unit of Heat.—A unit of heat (B. T. U.) is that quantity of heat that is required to raise the temperature of one pound of pure water one degree Fahrenheit, at or near 39 degrees Fahrenheit, the temperature of maximum density of water.

Mechanical work is measured in foot-pounds, and it has been determined that there are about 778 foot-pounds of energy in one heat unit.

Radiation of Heat.—Radiation of heat takes place between bodies at all distances apart, the rays proceeding in straight lines, and follows the laws of light radiation. It is believed that radiant heat and light are one and the same thing; that the former differs from the latter the same as the red rays of light differ from the blue rays, and that heat rays are not evident to the sense of sight because the eye is not susceptible to their vibrations, which are slower than light.

The rate at which a hot body radiates heat and a cold one absorbs it depends greatly on the condition of the surfaces of the bodies as well as their temperature, the rate being greatest with the greatest difference of temperature. The rate of radiation and absorption is increased by darkness and roughness of the surfaces of bodies, and diminished by smoothness and polish.

Conduction of Heat.—Conduction is the transfer of heat between two bodies or different parts of one body that touch each other or are in communication.

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CHEMISTRY.

Elements.—An element is a substance that cannot be decomposed into a simpler substance by any chemical or other process now known. As an example of elements there may be mentioned *carbon, iron, sulphur, hydrogen* and *nitrogen.* The number of elements thus far discovered is less than one hundred, but the greater number of these are rare.

Affinity.—Affinity is that molecular force or attraction that unites atoms of unlike elements or substances into compounds possessing new and distinct properties.

Compound.—A compound is a substance that can be decomposed into simpler ones, and it contains two or more elements held together chemically. While there are comparatively few elements met with in nature there are thousands of compounds, in fact, most substances that we come in contact with are compounds. As examples there may be mentioned a number of fuel compounds, termed *hydrocarbons, water* (H_2O), *carbon monoxide* (CO), and *carbon dioxide* (CO_2).

It should be understood that a compound is something entirely different from a mixture of substances. In a mixture the substances exist side by side, while in a compound the substances that are in combination are entirely changed, and they are so intimately combined that none of the constituent elements can be recognized by ordinary means. Most chemical changes taking place that locomotive engineers and firemen have to deal with involve a very few substances, though a knowledge of the elementary principles of chemistry contributes to an understanding of the process of combustion and enables them to obtain the most efficient results in fuel combustion.

Carbon.—Carbon occurs principally in combination with other elements and in fact is the central element in all organic matter, both vegetable and animal. In the free state, carbon exists as graphite (plumbago) and diamond. Coke and charcoal are nearly pure carbon, produced by distilling low volatile matter from coal and wood. Coal is composed principally of carbon.

Carbon has the power to combine with oxygen, and in doing so heat is generated. At ordinary temperatures it does not combine rapidly enough to be useful, but at high temperatures combination between carbon and oxygen takes place readily and rapidly. A pound of carbon represents a definite quantity of chemical energy which by the process of combustion and mechanical means can be converted into other forms, as steam, electricity, motion, etc.

After a given quantity of carbon has been burned, the resulting product no longer represents energy as the carbon did, for the energy was given up during the process of combination. Similarly, a body of water elevated to a given height represents a certain quantity of

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potential energy that can be used by allowing it to fall upon the vanes of a water wheel connected with machinery, but after the water has fallen it no longer has power to do work, that is, it has no energy.

Oxygen.—The element oxygen is a colorless, tasteless, inodorous gas, though if subjected to high pressure and low temperature it will liquefy. It is the most abundant of all elements, existing in a free state in the air, and in combination in water. It is the only element that supports combustion.

Hydrogen.—The element hydrogen is also a colorless gas. It unites with oxygen at high temperature, burns with a colorless or slightly blue flame, generating intense heat. Hydrogen forms about eleven per cent. of water, four and five-tenths per cent. of wood and two per cent. of coal.

Nitrogen.—The element nitrogen is a gas existing in the free state in the air, of which it forms about four-fifths. It is a dilutant in the air, rendering combustion less active than it would be in oxygen alone.

Water.—Water (H_2O) is a compound, formed by the chemical combination of oxygen and hydrogen, consisting by weight eight parts oxygen and one part hydrogen. It is almost incompressible, and it is a poor conductor of heat.

In the process of cooling water becomes denser until reaching a temperature of 39° F., its point of maximum density; cooling below this point causes it to expand until at 32° F. it freezes and becomes a solid, expanding considerably more in the process of freezing. Pipes are often burst by the expansion of water in them freezing.

When water at a temperature lower than 39° F. is heated it contracts and becomes denser until a temperature of 39° F. is reached, above which, if the application of heat is continued, it expands and becomes less dense, boiling at a temperature of 212° F., at atmospheric pressure.

Carbon Monoxide.—The compound carbon monoxide (CO) is a colorless, inodorous gas. At high temperature it has great attraction for oxygen; burns with a pale blue flame, forming carbon dioxide.

Carbon monoxide is formed when insufficient air is supplied to burning fuels containing carbon, as, for example, when a locomotive's grates become clogged with clinker or a too heavy bed of fuel is maintained, both preventing the required amount of air being drawn through the fire. Under these conditions, if air of sufficient temperature be admitted above the fire combination takes place between the escaping carbon monoxide and oxygen, forming complete combustion.

The forming of carbon monoxide is incomplete combustion and its escape in this state from a locomotive firebox results in great loss of heat, as one pound of carbon burned to carbon dioxide generates 14,500 heat units, while the same quantity of carbon burned to carbon monoxide generates only 4400 heat units, or less than one-third.

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Carbon Dioxide.—Carbon dioxide (CO_2) is the principal and most readily formed compound of carbon and oxygen. It is a colorless gas at ordinary temperatures, has a slightly acid taste and smell. It is incombustible and does not support combustion, for the reason that it already holds in combination all the oxygen it has the power to combine with; therefore it is the product of complete combustion resulting from conversion of the carbon's chemical energy into heat.

Atmosphere.—Air is composed of the gases oxygen and nitrogen; 21 parts oxygen and 79 parts nitrogen by volume; 23 parts oxygen and 77 parts nitrogen by weight. The air is not a compound, the composing elements existing separately, producing a mechanical mixture. It is known to extend at least 45 miles above the earth, and being a form of matter has weight, exerting at the surface of the earth a pressure of about 14.7 pounds per square inch.

COAL.

The United States Geological Survey suggests that coal may be graded most satisfactorily on the basis of the ultimate analysis, that establishes the ratio of hydrogen to carbon, the quotient of the percentage of C divided by the percentage of H, or $R = \frac{C}{H}$.

Classification of Coal.

CLASS.	CARBON HYDROGEN RATIOS $\left(\frac{C}{H}\right)$.	
Anthracite	over 30 to 30	
	30 to 26	
Semi-anthracite	26 to 23	
Semi-bituminous	23 to 20	
Bituminous	20 to 17	Gas Coal
	17 to 14.4	Gas Coal
	14.4 to 12.5	Coking Coal
	12.5 to 11.2	Coking Coal
Lignite	11.2 to 9.2	Black or Sub-bituminous Brown.

Characteristics of Different Coals.

Anthracite or Hard Coal.—It is the densest, hardest and most lustrous of all coals. It burns with little flame and no smoke, contains very little volatile combustible matter. It is found mostly in Pennsylvania, although to some extent in Colorado and Virginia.

Semi-anthracite.—Is not so dense nor so hard as true anthracite. Its percentage of volatile combustible matter is somewhat greater, and it ignites more readily.

Semi-bituminous.—Its general characteristics are similar to bitu-

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minous, though it is not so hard, its fracture is more cuboidal, and its percentage of volatile combustible matter is less. It kindles readily, burns quickly with a steady fire and is much valued as a steam coal. Gas and coking coals are found in this group.

Bituminous.—Is generally brittle with a bright pitchy or greasy luster, and rather fragile as compared with anthracite. It burns with a yellow smoky flame and on distillation gives hydrocarbon oils or tar.

Under the term "bituminous" are included a number of varieties of coal that differ materially under the action of heat, such as coking or caking coals, and free burning coals.

Coking coals are those that become pasty or semiviscid in a fire, and when heated in a closed vessel become partially fused into a mass of coherent coke. This property of coking, however, may become greatly impaired by weathering.

Gas coals contain a low percentage of ash and a high percentage of volatile matter.

Lignite.—There are many grades of lignites, ranging from brown, woody or earthy coals to black lignites, sometimes termed "sub-bituminous." The general characteristics of lignites are their tendency to slack quickly on exposure to the atmosphere, low heating values and the abnormally large amount of contained moisture, ranging from 10 to 20 per cent. When burned in locomotives, special appliances must be used and precautions observed to prevent throwing sparks and setting on fire adjacent land, forests and buildings.

COMPOSITION, HEAT VALUES, AND WEIGHTS OF FUELS.

The value of any fuel used in steam generating is measured by the number of heat units (B. T. U.'s) generated by its combustion. The heating value of all fuels depends upon the amount of the elements carbon and hydrogen they contain, either alone, together, or in combination.

One pound of pure carbon generates 14,500 B. T. U.'s when completely burned to CO_2, and requires about twelve pounds of air for its combustion. One pound of pure hydrogen generates 62,000 B. T. U.'s, requiring for its complete combustion about 36 pounds of air.

Solid fuels, such as coal and wood, contain, in addition to carbon and hydrogen, other substances which have no heating value, such as ash and water. Most coals also contain small quantities of sulphur (usually in the form of iron pyrites) and of nitrogen, which have no fuel value. The term *combustible* used in connection with fuels means the portion that will burn; the ash or residue from combustion of solid fuels varies from 2 to 36 per cent.

Liquid fuels, such as petroleum and its by-products, are nearly pure compounds of carbon and hydrogen. Gaseous fuels contain car-

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bon monoxide, hydrocarbon gases, and hydrogen as their heat generating constituents, and they also contain other substances of no fuel value, as carbon dioxide and nitrogen.

The following tables show composition, heating values, expressed in British thermal units, weights, and other useful information relating to different kinds and grades of fuels and American coals.

TABLE OF COMBUSTIBLES.

Kind of Combustible.	Air Required	Temperature of Combustion.				Theoretical Value.	
	In Pounds, per pound of Combustible	With Theoretical Supply of Air	With 1½ Times the Theoretical Supply of Air	With Twice the Theoretical Supply of Air	With Three Times the Theoretical Supply of Air	In Pounds of Water raised 1° per pound of Combustible	In Pounds of Water evaporated from and at 212°, with 1 lb. Combustible
Hydrogen	36.00	5750	3860	2860	1940	62032	64.20
Petroleum	15.43	5050	3515	2710	1850	21000	21.74
Carbon { Charcoal, Coke, Anthracite Coal, }	12.13	4580	3215	2440	1650	14500	15.00
Coal—Cumberland	12.06	4900	3360	2550	1730	15370	15.90
Coal—Coking Bituminous	11.73	5140	3520	2680	1810	15837	16.00
Coal—Cannel	11.80	4850	3330	2540	1720	15080	15.60
Coal—Lignite	9.30	4600	3210	2490	1670	11745	12.15
Peat—Kiln dried	7.68	4470	3140	2420	1660	9660	10.00
Peat—Air dried, 25% water	5.76	4000	2820	2240	1550	7000	7.25
Wood—Kiln dried	6.00	4080	2910	2260	1530	7245	7.50
Wood—Air dried, 20% water	4.80	3700	2607	2100	1490	5600	5.80

WEIGHT AND BULK OF COAL.

Bituminous			Pennsylvania Anthracite		
Name of Coal	Cubic Feet per Ton[1]	Weight per Cubic Foot Pounds	Commercial Size	Cubic Feet per Ton[1]	Weight per Cubic Foot Pounds
Pittsburgh	48.2	46.5	Broken	39.4	56.9
Erie	46.6	48.1	Egg	38.8	57.7
Hocking Valley	45.4	49.3	Stove	38.5	58.2
Ohio Cannel	45.5	49.2	Nut	38.4	58.3
Indiana	51.1	43.8	Pea	42.1	53.2
Illinois	47.4	47.2	Buckwheat	41.14	54.1
Average	47.37	47.3	Average	39.7	56.4

[1]Ton = 2240 lbs.

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PROXIMATE ANALYSES AND HEATING VALUES OF AMERICAN COALS.

	Moisture.	Volatile Matter.	Fixed Carbon.	Ash.	Sulphur.	Heating Value per lb. coal, heat units	Volatile Matter per cent. of combustible.	Heating Value per lb. combustible, heat units.	Theoretical Evaporation lbs. water from and at 212° per lb. combustible.
Anthracite:									
Northern coal field	3.42	4.38	83.27	8.20	.73	13,160	5.00	14,900	15.42
East Middle coal field	3.71	3.08	86.40	6.22	.58	13,420	3.44	14,900	15.42
West Middle coal field	3.16	3.72	81.59	10.65	.50	12,840	4.36	14,900	15.42
Southern coal field	3.09	4.28	83.81	8.18	.64	13,220	4.85	14,900	15.42
Anthracite from one mine:									
Egg.....Screen 2½"–1¾"	.....	.....	88.49	5.66	....	.....	.....	.....	.....
Stove.....Screen 1¾"–1¼"	.....	.....	83.67	10.17	....	.....	.....	.....	.....
Chestnut....Screen 1¼"– ¾"	.....	.....	80.72	12.67	....	.....	.....	.....	.....
Pea.....Screen ¾"– ½"	.....	.....	79.05	14.66	....	.....	.....	.....	.....
Buckwheat..Screen ½"– ¼"	.....	.....	76.92	16.62	....	.....	.....	.....	.....
Semi-Anthracite:									
Loyalsock field	1.30	8.10	83.34	6.23	1.63	13,920	8.86	15,500	16.05
Bernice basin	.65	9.40	83.69	5.34	.91	13,700	10.98	15,500	16.05
Semi-Bituminous:									
Broad Top, Pa	.79	15.61	77.30	5.40	.90	14,820	17.60	15,800	16.36
Clearfield County, Pa	.76	22.52	71.82	3.99	.91	14,950	24.60	15,700	16.25
Cambria County, Pa	.94	19.20	71.12	7.04	1.70	14,450	22.71	15,700	16.25

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Somerset County, Pa.	1.58	16.42	71.51	8.62	1.87	14,200	20.37	15,800	16.36
Cumberland, Md.	1.09	17.30	73.12	7.75	.74	14,400	19.79	15,800	16.36
Pocahontas, Va.	1.00	21.00	74.39	3.03	.58	15,070	22.50	15,700	16.25
New River, W. Va.	.85	17.88	77.64	3.36	.27	15,220	18.95	15,800	16.36
Bituminous:									
Connellsville, Pa.	1.26	30.12	59.61	8.23	.78	14,050	34.03	15,300	15.84
Youghiogheny, Pa.	1.03	36.50	59.05	2.61	.81	14,450	38.73	15,000	15.53
Pittsburgh, Pa.	1.37	35.90	52.21	8.02	1.80	13,410	41.61	14,800	15.32
Jefferson County, Pa.	1.21	32.53	60.99	4.27	1.00	14,370	35.47	15,200	15.74
Middle Kittanning seam, Pa.	1.81	35.33	53.70	7.18	1.98	13,200	40.27	14,500	15.01
Upper Freeport seam, Pa. and O	1.93	35.90	50.19	9.10	2.89	13,170	43.59	14,800	15.32
Thacker, W. Va.	1.38	35.04	56.03	6.27	1.28	14,040	39.33	15,200	15.74
Jackson County, O.	3.83	32.07	57.60	6.50	....	13,090	35.76	14,600	15.11
Brier Hill, O.	4.80	34.60	56.30	4.30	....	13,010	38.20	14,300	14.80
Hocking Valley, O.	6.59	34.97	48.85	8.00	1.59	12,130	42.81	14,200	14.70
Vanderpool, Ky.	4.00	34.10	54.60	7.30	....	12,770	38.50	14,400	14.91
Muhlenberg County, Ky.	4.33	33.65	55.50	4.95	1.57	13,060	38.86	14,400(?)	14.91
Scott County, Tenn.	1.26	35.76	53.14	8.02	1.80	13,700	34.17	15,100(?)	15.63
Jefferson County, Ala.	1.55	34.44	59.77	2.62	1.42	13,770	37.63	14,400(?)	14.91
Big Muddy, Ill.	7.50	30.70	53.80	8.00	....	12,420	36.30	14,700	15.22
Mt. Olive, Ill.	11.00	35.65	37.10	13.00	....	10,490	47.00	13,800	14.29
Streator, Ill.	12.00	33.30	40.70	14.00	....	10,580	45.00	14,300	14.80
Missouri	6.44	37.57	47.94	8.05	....	12,230	43.94	14,300(?)	14.80
Lignites and Lignitic Coals:									
Iowa	8.45	37.09	35.60	18.86	....	8,720	51.03	12,000(?)	12.42
Wyoming	8.19	38.72	41.83	11.26	....	10,390	48.07	12,900(?)	13.35
Utah	9.29	41.97	44.37	3.20	1.18	11,030	48.60	12,600(?)	13.04
Oregon Lignite	15.25	42.98	33.32	7.11	1.66	8,540	54.95	11,000(?)	11.39

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CYLINDER VOLUMES IN CUBIC FEET
(For One Cylinder Only)

Diameter Inches	Stroke in Inches												
	12	14	16	18	20	22	24	26	28	30	32	34	36
10	.550	.64	.72	.81	.90	....	....	.....	.....	.....	.....	.....	.....
10½	.601	.70	.80	.90	1.00	....	....	.....	.....	.....	.....	.....	.....
11	.660	.77	.88	.99	1.10	1.21	....	.....	.....	.....	.....	.....	.....
11½	.721	.84	.96	1.08	1.20	1.32	....	.....	.....	.....	.....	.....	.....
12	.780	.91	1.04	1.17	1.30	1.43	1.56	.....	.....	.....	.....	.....	.....
12½	.849	.99	1.13	1.27	1.41	1.55	1.69	.....	.....	.....	.....	.....	.....
13	....	1.07	1.23	1.39	1.54	1.69	1.85	.....	.....	.....	.....	.....	.....
13½	....	1.16	1.33	1.49	1.66	1.82	1.99	.....	.....	.....	.....	.....	.....
14	....	1.24	1.42	1.60	1.78	1.95	2.13	.....	.....	.....	.....	.....	.....
14½	....	....	1.53	1.72	1.91	2.10	2.29	.....	.....	.....	.....	.....	.....
15	....	....	1.63	1.84	2.04	2.24	2.45	2.65	.....	.....	.....	.....	.....
15½	....	....	1.74	1.96	2.18	2.40	2.62	2.84	.....	.....	.....	.....	.....
16	....	....	1.85	2.08	2.32	2.55	2.78	3.02	.....	.....	.....	.....	.....
16½	....	....	....	2.23	2.47	2.72	2.97	3.23	.....	.....	.....	.....	.....
17	....	....	....	2.38	2.64	2.90	3.17	3.43	3.69	.....	.....	.....	.....
17½	....	....	....	2.50	2.78	3.06	3.34	3.72	3.98	.....	.....	.....	.....
18	....	....	....	2.65	2.94	3.23	3.53	3.82	4.12	.....	.....	.....	.....
18½	....	....	....	....	3.11	3.42	3.73	4.04	4.35	.....	.....	.....	.....
19	....	....	....	....	3.28	3.61	3.94	4.26	4.59	4.92	.....	.....	.....
19½	....	....	....	....	3.46	3.80	4.15	4.50	4.84	5.19	.....	.....	.....
20	....	....	....	....	3.64	4.00	4.37	4.73	5.10	5.46	.....	.....	.....
20½	....	....	....	....	....	4.20	4.58	4.96	5.34	5.73	.....	.....	.....
21	....	....	....	....	....	4.40	4.80	5.20	5.60	6.00	6.42	.....	.....
21½	....	....	....	....	....	4.62	5.04	5.46	5.88	6.30	6.72	.....	.....
22	....	....	....	....	....	4.84	5.28	5.72	6.16	6.60	7.05	.....	.....
22½	....	....	....	....	....	....	5.52	5.98	6.44	6.90	7.36	.....	.....
23	....	....	....	....	....	....	5.76	6.24	6.72	7.20	7.68	8.18	.....
23½	....	....	....	....	....	....	6.02	6.52	7.02	7.52	8.02	8.52	.....
24	....	....	....	....	....	....	6.27	6.79	7.31	7.83	8.38	8.90	.....
24½	....	....	....	....	....	....	....	7.10	7.65	8.20	8.75	9.30	.....
25	....	....	....	....	....	....	....	7.38	7.95	8.52	9.08	9.65	10.21
25½	....	....	....	....	....	....	....	7.68	8.27	8.86	9.45	10.04	10.63
26	....	....	....	....	....	....	....	7.98	8.60	9.21	9.83	10.44	11.08
27	....	....	....	....	....	....	....	8.61	9.27	9.93	10.59	11.26	11.92
28	....	....	....	....	....	....	....	9.26	9.97	10.68	11.39	12.10	12.82
29	....	....	....	....	....	....	....	9.93	10.70	11.46	12.22	13.00	13.76
30	....	....	....	....	....	....	....	10.63	11.45	12.27	13.09	13.90	14.72
31	....	....	....	....	....	....	....	.....	12.23	13.10	13.97	14.84	15.71
32	....	....	....	....	....	....	....	.....	13.03	13.96	14.90	15.84	16.76
33	....	....	....	....	....	....	....	.....	13.85	14.84	15.82	16.82	17.81
34	....	....	....	....	....	....	....	.....	14.71	15.76	16.82	17.87	18.92
35	....	....	....	....	....	....	....	.....	15.59	16.70	17.81	18.92	20.10
36	....	....	....	....	....	....	....	.....	16.49	17.67	18.85	20.03	21.21
37	....	....	....	....	....	....	....	.....	17.42	18.67	19.91	21.15	22.40
38	....	....	....	....	....	....	....	.....	18.38	19.69	21.00	22.31	23.63
39	....	....	....	....	....	....	....	.....	.....	20.74	22.12	23.50	24.89
40	....	....	....	....	....	....	....	.....	.....	21.82	23.27	24.72	26.18
41	....	....	....	....	....	....	....	.....	.....	22.92	24.45	25.98	27.51
42	....	....	....	....	....	....	....	.....	.....	24.05	25.66	27.26	28.86
43	....	....	....	....	....	....	....	.....	.....	25.21	26.89	28.57	30.25
44	....	....	....	....	....	....	....	.....	.....	26.40	28.16	29.92	31.68
45	....	....	....	....	....	....	....	.....	.....	27.61	29.45	31.29	33.13

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REVOLUTIONS OF WHEELS PER MINUTE AND PER SECOND AT VARIOUS SPEEDS.

Wheels			For Rev. per minute, mult. miles per hour by	For Rev. per second, mult. miles per hour by
Diam. in Inches	Circum. in Feet	Revolutions per Mile		
18	4.71	1119.8	18.66	.3110
20	5.24	1008.4	16.81	.2801
22	5.76	916.8	15.28	.2547
24	6.28	838.4	13.97	.2329
26	6.81	775.3	12.92	.2153
28	7.36	720.3	12.00	.2000
30	7.85	672.6	11.21	.1868
32	8.38	630.3	10.50	.1751
33	8.64	611.1	10.18	.1696
34	8.90	593.2	9.89	.1648
36	9.42	560.5	9.34	.1556
37	9.69	545.1	9.09	.1514
38	9.95	530.6	8.84	.1440
40	10.47	504.2	8.40	.1401
42	11.00	480.0	8.00	.1363
44	11.52	458.3	7.64	.1273
46	12.04	438.5	7.31	.1218
48	12.57	420.0	7.00	.1166
50	13.00	403.4	6.72	.1120
52	13.61	387.9	6.46	.1073
54	14.14	373.4	6.22	.1033
56	14.66	360.2	6.00	.1000
58	15.18	347.8	5.79	.0965
60	15.71	336.1	5.60	.0933
62	16.23	325.3	5.42	.0903
64	16.75	315.2	5.25	.0875
66	17.28	305.5	5.09	.0848
68	17.80	296.6	4.94	.0823
70	18.36	288.1	4.80	.0798
72	18.85	280.1	4.67	.0778
78	20.42	258.6	4.31	.0718
84	21.99	240.1	4.00	.0666
90	23.56	224.1	3.73	.0622
96	25.16	210.1	3.50	.0586

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SPEED, SECONDS PER MILE IN MILES PER HOUR.

Seconds per Mile	Miles per Hour	Seconds per Mile	Miles per Hour	Seconds per Mile	Miles per Hour	Seconds per Mile	Miles per Hour
24	150.0	54	66.6	84	42.8	114	31.6
25	144.0	55	65.4	85	42.3	115	31.3
26	138.5	56	64.3	86	41.8	116	31.0
27	133.3	57	63.1	87	41.3	117	30.7
28	128.5	58	62.0	88	40.9	118	30.5
29	124.1	59	61.0	89	40.4	119	30.2
30	120.0	60	60.0	90	40.0	120	30.0
31	116.1	61	59.0	91	39.5	121	29.7
32	112.5	62	58.0	92	39.1	122	29.5
33	109.0	63	57.1	93	38.7	123	29.2
34	105.8	64	56.2	94	38.3	124	29.0
35	102.8	65	55.3	95	37.9	125	28.8
36	100.0	66	54.5	96	37.5	126	28.6
37	97.3	67	53.7	97	37.1	127	28.3
38	94.7	68	52.9	98	36.7	128	28.1
39	92.3	69	52.1	99	36.4	129	27.9
40	90.0	70	51.4	100	36.0	130	27.7
41	87.8	71	50.7	101	35.6	132	27.2
42	85.7	72	50.0	102	35.3	134	26.8
43	83.7	73	49.3	103	34.9	136	26.4
44	81.8	74	48.6	104	34.6	138	26.0
45	80.0	75	48.0	105	34.3	140	25.7
46	78.2	76	47.3	106	34.0	142	25.3
47	76.6	77	46.7	107	33.7	144	25.0
48	75.0	78	46.1	108	33.4	146	24.6
49	73.4	79	45.5	109	33.0	148	24.3
50	72.0	80	45.0	110	32.7	150	24.0
51	70.5	81	44.4	111	32.4	152	23.6
52	69.2	82	43.9	112	32.1	154	23.3
53	67.9	83	43.3	113	31.8	156	23.1

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SPEED, TIME PER MILE, FEET PER SECONDS.

Miles per Hour	Time per Mile Min.	Sec.	Feet per Second
8	7	30.0	11¾
15	4	0.0	22
16	3	45.0	23½
17	3	31.8	25
18	3	20.0	26½
19	3	9.5	28
20	3	0.0	29¼
21	2	51.4	30¾
22	2	43.6	32¼
23	2	36.5	33¾
24	2	30.0	35¼
25	2	24.0	36¾
26	2	18.5	38¼
27	2	13.2	39½
28	2	8.6	41
29	2	4.1	42½
30	2	0.0	44
31	1	56.2	45½
32	1	52.5	47
33	1	49.1	48½
34	1	45.8	50
35	1	42.7	51¼
36	1	40.0	52¾
37	1	37.3	54¼
38	1	34.8	55¾
39	1	32.3	57¼
40	1	30.0	58¾
41	1	27.8	60¼
42	1	25.7	61½
43	1	23.7	63
44	1	21.8	64½
45	1	20.0	66
46	1	18.2	67½
47	1	16.6	69
48	1	15.0	70½
49	1	13.5	71¾
50	1	12.0	73¼
51	1	10.6	74¾
52	1	9.2	76¼
53	1	7.9	77¾
54	1	6.7	79¼
55	1	5.5	80¼
56	1	4.3	82¼
57	1	3.2	83½
58	1	2.1	85
59	1	1.0	86½
60	1	0.0	88
61		59.0	89½
62		58.0	91
63		57.1	92½
64		56.2	94
65		55.4	95¼
66		54.5	96¾
67		53.7	98¼
68		52.9	99¾
69		52.1	101½
70		51.4	102¾
71		50.7	104¼
72		50.0	105½
73		49.3	107
74		48.6	108½
75		48.0	110
76		47.3	111½
77		46.7	112¾
78		46.1	114¼
79		45.5	115½
80		45.0	117
81		44.4	118¾
82		43.9	120¼
83		43.4	121¾
84		42.8	123¼
85		42.3	124¾
86		41.8	126¼
87		41.3	127¾
88		40.8	129
89		40.4	130½
90		40.0	132
91		39.5	133½
92		39.1	135
93		38.7	136½
94		38.2	137¾
95		37.8	139¼
96		37.5	140¾
97		37.1	142¼
98		36.7	143¾
99		36.4	145¼
100		36.0	146½
101		35.6	148¼

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PART IV

STEAM

PHYSICAL PROPERTIES, FORMATION OF STEAM, WORK DONE BY STEAM DURING FORMATION, EXPANSION OF STEAM, CYLINDER CONDENSATION AND RE-EVAPORATION IN THE CYLINDER, SUPERHEATED STEAM.

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PHYSICAL PROPERTIES.

STEAM is a vapor or gas resulting from a conversion of water through the application of heat. Its most prominent features are capacity for absorbing a great quantity of heat during the act of conversion, great expanding force, and condensing when heat is abstracted.

It should be thoroughly understood that, considered from an abstract, steam engineering basis, steam is only a vehicle or medium that transports heat from a source to a machine suitable for transmuting heat into mechanical energy; therefore, the steam engine is virtually a heat engine, a machine for converting heat into work. And, further, it should be remembered that heat is a living force or form of energy, owing to certain motions of the molecules of matter, that can be and is measured in quantitive units, and that it and mechanical work are convertible.

In every heat engine there is a *working substance,* usually a fluid, which alternately takes in and rejects heat. A convenient approach to the theory of heat engines is to consider, first, the action of an engine in which the working substance is any one of the so-called permanent gases, or a mixture of them, such as air. Permanent gas, in this connection, means that the gas liquefies with difficulty—only by subjecting it to extremely low temperature in conjunction, usually, with high pressure. And so long as such gases are under conditions of pressure and temperature that differs from those extremes that produce liquefaction, they approximately conform to certain simple laws—laws that may be regarded as rigorously applicable to ideal substances called *perfect gases.* The laws that follow are nearly though not absolutely true for air, oxygen, nitrogen, hydrogen, and carbonic oxide, except at very low temperature and very high pressure as just noted, and may be regarded as strictly true of an ideal perfect gas.

Law 1 (*Boyle's Law*).—The volume of a given mass of gas varies inversely as the pressure, provided the temperature be kept constant.

This law means, if V be the volume of a given quantity of gas, and P the pressure, then so long as the temperature remains unchanged, V varies inversely as P, or P V = constant. For example, suppose a volume V = 1 cu. ft. of steam at 215 lbs. pressure absolute be allowed to expand without loss of temperature to a greater volume V″, say to 4 cu. ft., then the original pressure P, 215 lbs., will become P″, thus

$$\begin{aligned} V &= 1 \\ P &= 215 \\ V'' &= 4 \end{aligned}$$

$$\text{Thence} \quad P'' = \frac{PV}{V''} = \frac{215 \times 1}{4} = 53.75,$$

$$P'' = 53.75 \text{ lbs.}$$

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Law 2 (*Charles's Law*).—Under constant pressure equal volumes of different gases increase equally for the same increment of temperature. Also, if a gas be heated under constant pressure, equal increments of its volume correspond very nearly to equal intervals of temperature as determined by the scale of a mercury thermometer.

This law means, if a quantity of air at a given temperature contained in a vessel be heated, provision being made so that the air may expand without any change in pressure, the volume of air will increase, and the increase in volume is approximately proportional to the magnitude of the interval of temperature as measured on the scale of an ordinary mercury thermometer. Any other permanent gas may be substituted for air in the vessel, and the volume will change sensibly the same amount as with air.

Experiment shows that the amount by which a gas expands when its temperature changes by one degree Fahrenheit, the pressure being kept constant, is about $\frac{1}{493}$ of its volume at 32° F. Thus, 493 cubic inches of air or any other permanent gas at 32° heated to a temperature of 33° increases in volume to 494 cubic inches. If heated to 34° its volume becomes 495 cubic inches and so on. Similarly, if the gas be cooled from 32° F. to 31° F., its volume decreases from its original 493 cubic inches to 492, and so on.

Tabulating this, let the volume be

	493 at 32° F.
It will become	492 at 31° F.
	. .
	. .
	. .
	461 at 0° F.
	. .
	. .
	. .
And finally, would be	0 at −461° F.,

if the same law held good at indefinitely low temperatures. But any actual gas changes its state before so low a temperature is reached. The preceding proposition may be concisely expressed by saying that if temperature be reckoned, not from the zero point on the Fahrenheit scale, but from a point 461° below it, the volume of a given quantity of gas, kept at constant pressure, is proportional to the temperature reckoned from that zero. Temperatures so reckoned are termed "absolute temperatures," and the point on the Fahrenheit scale —461° is called absolute zero of temperature.

As our subject-matter concerns heat engines in which the working substance is water and water-vapor or steam, and as a preliminary to what happens when steam is formed under "constant pressure," substantially the process that occurs in the boiler of a steam engine

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when the engine is at work, the following notes and tables on the physical properties of steam as determined by experiment will be presented.

Saturated Steam.—Saturated steam is steam of a temperature due to its pressure—not superheated. Any vapor in contact with its liquid and in thermal equilibrium is necessarily saturated.

NOTE.—Some persons are of the opinion that steam in a saturated state is wet, but this is erroneous.

Superheated Steam.—Superheated steam is steam heated to a temperature higher than that due to its pressure. The properties of saturated steam differ considerably, as a rule, from those of a perfect gas, but when superheated they approach those of a perfect gas more and more closely the farther the process of superheating is carried. While saturated steam at a given pressure can have but one temperature, superheated steam at the same pressure can have any temperature higher. See Superheating later on in this chapter.

Latent Heat of Steam.—Latent heat of steam is the quantity of heat that apparently disappears when water is converted into steam. In the conversion it is not only necessary to bring the water to the boiling temperature, but even after that temperature has been reached the application of heat must be continued in order to maintain the process of boiling. Part of this latent heat disappears in the process of conversion and the other part disappears in doing the work of increasing the small volume of water into the relatively great volume of steam—*i.e.*, the steam must make room for itself against pressure of the surrounding atmosphere (or steam if inclosed in a vessel). The amount of heat rendered latent by each pound of water in becoming steam varies at different pressures, decreasing as the pressure increases. The latent heat added to the sensible heat (or the thermometric temperature) constitutes the *Total Heat* of steam, and the total heat becoming greater as pressure increases, it requires more heat and consequently more fuel to make a pound of steam the higher the pressure.

The Temperature of Steam.—The temperature of steam depends on the pressure at which it is generated, the steam and water in a boiler being of the same temperature. At atmospheric pressure (14.7 lbs. the sq. in.) its temperature is 212° F., and as pressure increases, its temperature, and that of the water in contact with it, also increases, though not proportionately.

Dry Steam.—Dry steam is steam that contains no moisture. It may be either saturated or superheated.

Wet Steam.—Wet steam is steam containing intermingled moisture, mist, or spray. Wet steam, the result of either priming or foaming, may be caused by impure water, too much water or an improperly proportioned boiler.

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Relative Volume of Steam.—The relative volume of steam is the number of volumes of steam produced from one volume of water at a given pressure. One cubic inch of water makes 1646 cubic inches of steam.

PROPERTIES OF SATURATED STEAM.

Vacuum Gauge, Inches of Mercury.	Absolute Pressure, lbs. per sq. in.	Temperature, Fahrenheit.	Total Heat above 32° F.		Latent Heat L = H-h. Heat Units.	Relative Volume. Vol. of Water at 39° F = 1.	Volume, cu. ft. in 1 lb. of Steam.	Weight of 1 cu. ft. Steam, lbs.
			In the water h Heat-units	In the steam H Heat-units				
29.74	.089	32	0	1091.7	1091.7	208080	3333.3	.00030
19.74	5	162.3	130.7	1131.4	1000.7	4530	72.5	.01373
9.56	10	193.2	161.9	1140.9	979.0	2361	37.8	.02641
Gauge Pressure lbs. per sq. in.	14.7	212	180.9	1146.6	965.7	1646	26.4	.03794
0.3	15	213	181.9	1146.9	965.0	1614	25.9	.03868
5.3	20	227.9	197.0	1151.5	954.4	1231	19.7	.05070
15.3	30	250.2	219.7	1158.3	938.9	841	13.5	.07420
25.3	40	267.1	236.9	1163.4	926.5	642	10.3	.09721
35.3	50	280.9	251.0	1167.6	916.6	520	8.3	.11980
45.3	60	292.5	262.9	1171.2	908.2	438	7.0	.14220
55.3	70	302.7	273.4	1174.3	900.9	379	6.1	.16430
65.3	80	311.8	282.7	1177.0	894.3	334	5.4	.18620
75.3	90	320.0	291.2	1179.6	888.4	299	4.8	.20800
85.3	100	327.0	298.9	1181.8	882.9	271	4.4	.22960
95.3	110	334.5	306.1	1184.0	877.9	247	4.0	.25100
105.3	120	341.0	312.8	1185.9	873.2	228	3.7	.27240
115.3	130	347.1	319.1	1187.8	868.7	211	3.4	.29360
125.3	140	352.8	325.0	1189.5	864.6	197	3.2	.31470
135.3	150	358.2	330.6	1191.2	860.6	185	3.0	.33580
140.3	155	360.5	333.2	1191.9	858.6	179	2.9	.34675
145.3	160	363.3	335.9	1192.7	856.9	174	2.8	.35670
155.3	170	368.2	340.9	1194.2	853.3	164	2.6	.37750
160.3	175	370.5	343.4	1194.9	851.6	160	2.5	.38790
165.3	180	372.8	345.8	1195.7	849.9	156	2.5	.39830
175.3	190	377.3	350.4	1197.0	846.6	148	2.4	.41910
180.3	195	379.5	352.7	1197.7	845.0	144	2.3	.42960
185.3	200	381.6	354.9	1198.3	843.4	141	2.3	.44000
195.3	210	385.7	359.2	1199.6	840.4	134	2.2	.46050
200.3	215	387.7	361.3	1200.2	838.8	131	2.1	.47070
205.3	220	389.7	362.2	1200.8	838.6	128	2.1	.48520
215.3	230	393.6	366.2	1202.0	835.8	123	2.0	.50610
225.3	240	397.3	370.0	1203.1	833.1	118	1.9	.52700
235.3	250	400.9	373.8	1204.2	830.5	114	1.8	.54780
245.3	260	404.4	377.4	1205.3	827.9	109	1.8	.56860
250.3	265	406.1	379.1	1205.8	826.6	107	1.7	.58940

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PROPERTIES OF SUPERHEATED STEAM.

Boiler Pressure lbs. per Sq. Inch	Superheat, Degrees F.	Temp. of Steam Degrees F.	Total Heat B. T. U.'s per Pound	Specific Volume, Cubic Feet per Pound	Increase in Volume over Sat. Steam per cent.
150	25	390.9	1210.6	2.87	4.4
	50	415.9	1225.2	2.99	8.7
	75	440.9	1238.8	3.10	12.7
	100	465.9	1252.0	3.21	16.7
	150	515.9	1277.6	3.43	24.7
	200	565.9	1302.5	3.64	32.4
160	25	395.8	1211.8	2.72	4.5
	50	420.7	1226.6	2.83	8.9
	75	445.7	1240.3	2.93	12.6
	100	470.7	1253.6	3.04	16.9
	150	520.7	1279.1	3.24	24.6
	200	570.7	1304.1	3.44	32.3
170	25	400.3	1213.0	2.58	4.4
	50	425.3	1227.9	2.68	8.5
	75	450.3	1241.7	2.78	12.5
	100	475.3	1255.0	2.89	17.0
	150	525.3	1280.6	3.08	24.8
	200	575.3	1305.6	3.27	32.4
180	25	404.6	1214.2	2.45	4.3
	50	429.6	1229.2	2.55	8.5
	75	454.6	1243.1	2.65	12.8
	100	479.6	1256.4	2.75	17.0
	150	529.6	1282.0	2.93	24.7
	200	579.6	1307.0	3.11	32.3
190	25	408.8	1215.2	2.34	4.4
	50	433.8	1230.4	2.44	8.9
	75	458.8	1244.4	2.53	13.0
	100	483.8	1257.7	2.62	17.0
	150	533.8	1283.3	2.80	25.0
	200	583.8	1308.3	2.97	32.7
200	25	412.9	1216.3	2.23	4.3
	50	437.9	1231.6	2.33	8.9
	75	462.9	1245.6	2.42	13.1
	100	487.9	1259.0	2.51	17.3
	150	537.9	1284.6	2.68	25.2
	200	587.9	1309.7	2.84	32.7

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FORMATION OF STEAM.

The chemical compound known as H_2O can exist in three states or conditions—ice, water and steam—the particular state at any time being controlled by the presence or absence of energy, partly in the form of heat and partly in molecular activity. To effect transformation from any one of these states to another it is only necessary to supply or abstract heat. For example, consider a pound of ice at absolute zero (461 degrees below zero Fahrenheit) contained in a vessel placed over a flame.

Flame is a result of the combining of oxygen, carbon and hydrogen. In this combining process atoms of the respective elements rush together and the resulting molecules acquire great velocity. This great rate of molecular motion is what is recognized as high temperature, and such combination is commonly known as combustion.

The first effect on the pound of ice by the flame is to raise its temperature, becoming warmer till it reaches a temperature 493 degrees above the starting point, or at 32° F. At this point it stops growing warmer, even though the application of heat is continued; but its state changes from ice to water, and the continued application of heat will not raise the temperature above 32 degrees until all of the ice has been converted into water.

If the application of heat is still continued to what has now become one pound of water at 32 degrees, the water grows warmer. The molecules of the containing vessel move at a rate corresponding with a temperature of 32 degrees, the temperature of the water; while the molecules of the flame have a much greater velocity, their rate of motion corresponding to a temperature of 2000 degrees or more. Of course, when a swiftly moving body meets a slowly moving one, the slow one is hurried and the swift one loses the energy that the other gains. Analogously, the molecules of the vessel are accelerated (their temperature is raised), those of the gaseous products of combustion are retarded (their temperature lowered), and this condition of acceleration is communicated to the water in the vessel increasing its temperature. When the one pound of water reaches a temperature of 212 degrees, the molecules have attained a velocity that relates to this temperature, another critical point. If the process is conducted with the water under an absolute or atmospheric pressure of 14.7 pounds, the temperature stops increasing at 212 degrees and the water boils; the repellent force overcomes the attractive force of the whirling molecules and they fly out from each other, battering back the surrounding wall of water, and form bubbles of steam.

Another example of the formation of steam under constant pressure may be illustrated by the following diagrams.

Let the cylinder (*a*, Fig. 26) contain 1 pound of water at 32° F.

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and let the pressure of the atmosphere be represented by a frictionless, weighted piston. Then, if heat be applied, as it enters the water it will produce the following effects in three stages:

(1) The temperature of the water rises, though the piston will remain stationary, except for the slight expanding of the water, until the temperature of the water reaches 212°.

(2) On continuing the heat steam is formed, and the piston ascends in the cylinder (*b*, Fig. 26). But no further increase in temperature occurs during this stage, which continues until all the water is converted into steam. In stage 1 steam did not begin to form until the temperature reached 212°, and so it is evident that this

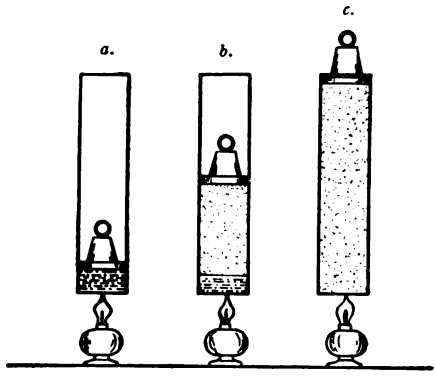

FIG. 26.—Formation of steam.

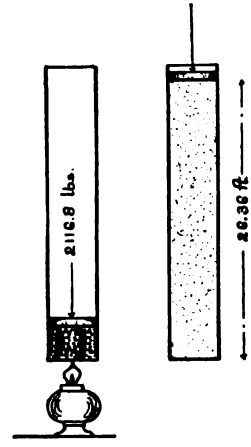

FIG. 27.—Work done during formation of steam.

is the lowest temperature at which steam can exist under a pressure equal to atmospheric.

As soon as the last drop of water is converted into steam (*c*, Fig. 26), the steam occupies the least possible volume at the given pressure, and in this condition it is termed *saturated* steam.

(3) If after all the water is converted into steam the heat is continued, the steam's temperature and volume will increase and the piston will continue to rise. The steam then becomes *superheated.*

WORK DONE BY STEAM DURING FORMATION.

The quantities of heat required and the work performed in the several stages of steam forming are presented in the following diagrams and tabulated statements:

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Assume that the cylinder, Fig. 27, of a sectional area of 1 square foot, contains 1 pound of water at 32°; that the pressure of the atmosphere is represented by a frictionless piston resting on the surface of the water loaded with a weight of 14.7 pounds per square inch, which would be a total weight of 2116.8 pounds.

On applying heat to the water, its temperature will increase from 32° to 212° before evaporation begins, as explained under stage 1.

A heat unit (B. T. U.) is defined as the quantity of heat required to raise the temperature of 1 pound of water 1 degree, at or near 39° F., and if this feature were constant, that is, if it required the same quantity of heat to raise 1 pound of water from 211 to 212 as from 39 to 40, it would require $212 - 32 = 180$ B. T. U.'s to raise the pound of water to 212 degrees, the boiling point; but at the higher temperature it requires more heat to raise a pound of water 1 degree than at the lower, for in the table "Properties of Saturated Steam" it is shown that 180.9 heat units are required to raise the temperature of one pound of water from 32 to 212 degrees, and this represents the heat units expended in stage 1, Fig. 26.

At 212° steam forms, the piston begins to rise. On continuing the heat, the water eventually is all converted into steam at 212°, and the piston continues rising till the steam occupies a volume of 26.36 cubic feet at atmospheric pressure. The total heat required, first to raise the water's temperature from 32° to 212°, and then to convert it into steam at the same temperature, is 1146.6 units; for while it requires 180.9 B. T. U.'s to raise the temperature of the one pound of water to 212°, it requires 965.7 more of the same units to boil it away, though the sensible temperature will remain at 212 degrees. These 965.7 units of heat that seemingly disappear are termed *latent heat.*

At atmospheric pressure steam occupies a volume 1646 times as great as the water from which it was generated. The heat that apparently disappears, latent heat, has been expended in two ways: First, in overcoming the resistance of molecular attraction in the water; second, in overcoming the external resistance of the piston to the steam's increasing volume during formation. It is important to distinguish between the character of these two effects. In the first the latent heat represents energy contained within the steam, the work performed being termed *internal,* because changes have been wrought within the body. In the second the latent heat represents energy that has passed out of the steam, performing *external* work, for work has been done on bodies external to itself, moving the piston in this case.

The heat expended in each phase of the process of evaporating the pound of water and raising the piston as just described follows: That expended in doing the external work of raising the piston under a pressure of 2116.8 lbs. through a height of 26.36 ft. $= 2116.8 \times$

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$26.36 = 55{,}799$ ft. lbs.; or $55{,}799 \div 778 = 71.7$ units of heat. As the total heat applied to the water is 1146.6 units, and as 252.6 ($180.9 + 71.7$) units are so far accounted for, there remains the difference of $1146.6 - 252.6 = 894$ units. These 894 units represent the heat expended in doing the internal work of converting the water into steam.

Summary of heat required to generate 1 pound of steam from water at 32° F.:

Sensible heat, to raise temperature of water from 32° to 212°		180.9
Latent heat (1), in overcoming internal resistance...	894.0	
(2) of external work of expanding against atmospheric pressure, 2116.4 lbs. per sq. ft. × 26.36 cu. ft. = 55,799 ft. lbs. ÷ 788 = ...	71.7	965.7
Total heat above 32°F.....		1146.6

In the preceding paragraphs on steam formation it surely will be noticed that the boiling point of water is controlled by a definite relation between pressure and temperature. In fact, every given pressure of steam has a corresponding water boiling temperature, and any temperature above 32 degrees will boil water provided it is under proper pressure. At a pressure of 0.089 pound absolute, very nearly a vacuum, water actually boils at a temperature of 32 degrees, for the reason that at this low temperature it is easier for the molecules to separate and move in greater circles. As pressure on the water is increased the temperature at which it boils also increases, and so at a pressure of 215 pounds absolute (200.3 gauge) the boiling temperature is 387.7 degrees.

EXPANSION OF STEAM.

When steam engines are required to exert their full power, as locomotives are required to do for short periods of time when starting trains or when pulling heavy trains up steep grades, steam is admitted to the cylinder at boiler pressure for practically the full stroke of the piston, without regard to economy in consumption of steam or fuel. And while extra work can be obtained from an engine by using steam in this manner, the steam and fuel consumption compared with that used when the steam is worked expansively becomes excessive.

Assume that a quantity of steam at a pressure of 215 pounds absolute (about 200 gauge) is contained to the left of the piston, which has made one-quarter stroke in the cylinder, Fig. 28, and further that

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this cylinder is made of material impervious to and unaffected by heat, capable of neither absorbing, transmitting nor giving it up, so that there will positively be no exchange of heat between the steam and the cylinder walls. If the piston be allowed to move to the end of its stroke, the steam expands and the original becomes four volumes. And if the temperature were kept constant, the pressure would be reduced to 53.75 pounds absolute. This mode of expansion is termed *isothermal,* which signifies constant temperature; for there is neither increase nor decrease in temperature—the velocity of the molecules continues constant.

But steam has inertia, and in the act of expanding work is performed, the steam's stock of internal energy—heat—is reduced, the temperature (to which the internal energy is proportional) falls, resulting at the end of expansion in a pressure considerably lower than

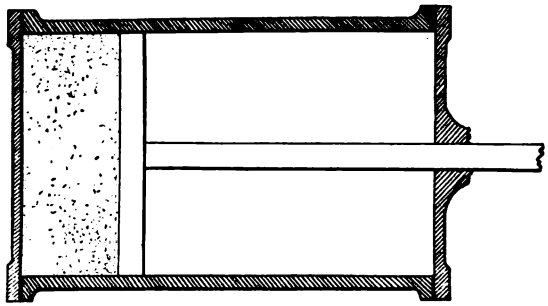

FIG. 28.—Expansion of steam in a cylinder.

one-fourth. This mode of expansion is termed *adiabatic,* and if the initial steam were dry saturated steam it is precisely the method that would obtain were expansion to take place in an ideal cylinder, one made of non-conducting material, which would permit of no transfer of heat to or from the steam.

The pressure-volume relations of both modes of expansion can be represented graphically by constructing theoretic diagrams, similar to those made by a steam-engine indicator, of which Fig. 29 is an example. This diagram shows the pressure-volume relation of steam admitted to a cylinder at 215 pounds absolute (about 200 gauge), the supply cut-off at one-quarter stroke and allowed to expand behind the piston the remainder of the stroke. Both modes of expansion are shown by curves, but as the curve of isothermal expansion is more easily compared with actual curves taken by indicators and is sufficiently accurate for all practical purposes, no values will be given for the adiabatic curve, though its position enables an approximation.

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The vertical line, ordinate, o Y, represents pressure, o being at the absolute zero of pressure, or gauge minus atmospheric pressure, and Y equals 215 pounds. At points drawn to scale on line o Y intermediate pressures are shown. The horizontal line o X, abscissa, divided off by equal spaces, 1, 2, 3, 4, represents volumes. The rectangle o Y A 1 represents one volume of steam, o Y B 2 two volumes, etc. The height of the heavy line indicates the pressure, which is constant Y to A as steam is flowing to the cylinder from the boiler. At A the piston has made one-quarter of its stroke; the supply of steam is then cut off by the valve, and the steam by its inherent expansive properties continues to force the piston onward in its stroke, though with continually decreasing pressure, as shown by the

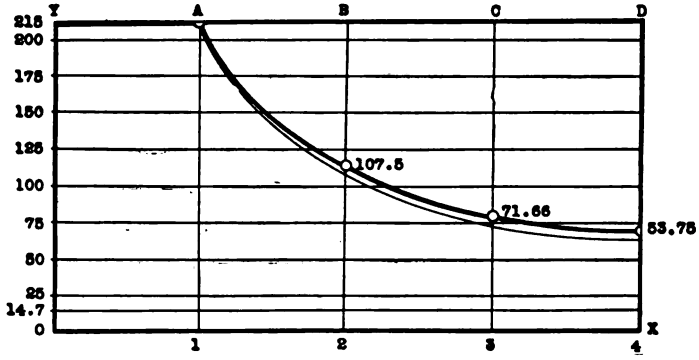

FIG. 29.—Diagram showing pressure-volume relation of steam during admission and expansion.

downward curve of the heavy line. This curve at its intersection with ordinate 2 B indicates only one-half the pressure at A, one-third on ordinate 3 C and one-fourth on 4 D.

During isothermal expansion the steam suffers no change of internal energy, and so the steam must absorb an amount of heat equal to that expended in the work being done. When this mode of expansion takes place, it is said the pressure varies as the volume, *i.e.*, if the volume is doubled, the pressure is halved; if trebled, pressure is reduced to one-third, and if the volume is quadrupled the resulting pressure is one-quarter. Beginning with one volume at 215 pounds we have the following relations:

(A) $215 \div 1 = 215$ pounds.
(B) $215 \div 2 = 107.5$ pounds.
(C) $215 \div 3 = 71.66$ pounds.
(D) $215 \div 4 = 53.75$ pounds.

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If expansion takes place adiabatically, no heat from an external source reaching the expanding steam, a part of the steam is condensed, forming either minute particles of water suspended throughout the mass or a dew on the walls of the cylinder. And while temperature and pressure fall, that part of the steam that remains uncondensed is saturated, and the temperature to pressure relation is that that holds for saturated steam.

The expansion line drawn by the steam-engine indicator applied to the average steam cylinder follows the curve of isothermal expansion nearer than any other. The explanation for this is, that in the actual steam cylinder the quantity of steam is not constant; that steam, usually containing more or less moisture on arrival in the cylinder, comes in contact with surfaces that have just been exposed to the comparatively cool exhaust, and is condensed upon them so that at the beginning of expansion the cylinder contains a mixture of steam and hot water, instead of saturated steam. As the pressure—also temperature—lowers during expansion the water is re-evaporated, replenishing the loss in volume owing to cooling and condensation.

CYLINDER CONDENSATION AND RE-EVAPORATION IN THE CYLINDER.

During the phases of admission, expansion, and exhaust taking place in the cylinder of a steam engine, the steam pressure continually varies between the limits of boiler pressure and the low pressure occurring during exhaust. At the same time the temperature of the steam fluctuates in unison with the pressure variations, no matter how rapidly they may occur, for steam has a temperature relation corresponding to its pressure. These temperature changes cause a complex give-and-take of heat between the steam and metal surfaces of the cylinder and piston, which are good conductors of heat, and the effects of this result in greatly reduced efficiency owing to increased consumption of steam.

When saturated steam is admitted at the beginning of a stroke, it finds the metal surfaces of the cylinder and piston chilled, owing to having been exposed to the lower temperatured, low-pressure exhaust steam of the previous stroke, and a portion of it is at once condensed. As the piston advances, more and more of the chilled cylinder surface becomes exposed and more and more of the steam condenses. At the point of cut-off, the cylinder contains a film of water spread over the exposed interior surfaces, and so the boiler must furnish a greater volume of steam during the period of admission than that that corresponds to the volume of admission space. After the period of admission, expansion begins, and more comparatively cold metal surface is uncovered, resulting in continued condensation. During the

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period of expansion additional condensation takes place owing to the work done by the steam in the act of expanding, a condensation that takes place even if the walls of the surrounding surfaces are perfect non-conductors. The condensation accumulating from these two actions combined causes the steam to get wet rapidly in the early stages of expansion, but the pressure of steam now falls—the temperature, too—and the film of water previously deposited, absorbing heat from the surrounding metal, begins to re-evaporate as soon as the temperature of the expanding steam becomes lower than that of these metal surfaces. Hence, while condensation increases during the earliest stage of expansion, a point is soon reached when the condensation that occurs on the newly exposed metal surfaces or throughout the steam as a whole is equalled by the re-evaporation taking place. At this point the percentage of water is a maximum, and from this point onward the steam becomes drier.

Re-evaporation may continue during exhaust, for if the amount of initial condensation is relatively large—in locomotive cylinders it usually is—it may not be complete before release occurs, and the process continues during the return stroke, while exhaust is taking place. The water that is re-evaporated during expansion and also exhaust obtains the requisite heat from the metal of the cylinder and piston, bringing them to a state that makes condensation inevitable when steam is next admitted. It is this continued process of condensation and re-evaporation that causes the exchange of heat between the metal of the cylinder and the working medium, steam. For mere contact with low-pressure steam during the later stages of expansion or during exhaust would cool the metal but very little if the surfaces were dry, as communication of heat between such surfaces and any gaseous substance is very slow even when the difference in temperature between them is great.

Condensation, then, takes place during the early part of the stroke, while re-evaporation occurs towards the end of the stroke and may continue partly during exhaust. The steam re-evaporated during expansion assists the piston and does useful work, but that re-evaporated during exhaust in the cylinder of a simple engine is wasted. Condensation in the cylinder increases as the degree of expansion increases, for the temperature of saturated steam varies with the pressure, and so if steam at high pressure and temperature be admitted to the cylinder and expanded to a low pressure—the temperature suffering a corresponding reduction—then the greater the degree of expansion the greater the difference in temperature between the initial steam and the mean temperature of the cylinder walls. And so there is a limit to the degree of useful expansion of steam in a single cylinder, owing to condensation, and with high degree of expansion excessive condensation takes place, resulting in increased fuel consumption instead of a saving. That this feature is of importance becomes obvious

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when the fact is known that the amount of steam so condensed during the period of admission sometimes reaches 50 per cent. of the quantity used. The following table shows the per cent. of condensation taking place in locomotive cylinders at various points of cut-off:

Condensation = 35	per cent.	at	20½	per cent.	cut-off.
Condensation = 25	per cent.	at	25	per cent.	cut-off.
Condensation = 20.5	per cent.	at	30	per cent.	cut-off.
Condensation = 16.5	per cent.	at	35	per cent.	cut-off.
Condensation = 16	per cent.	at	40	per cent.	cut-off.
Condensation = 14	per cent.	at	50	per cent.	cut-off.
Condensation = 13	per cent.	at	60	per cent.	cut-off.
Condensation = 12	per cent.	at	70	per cent.	cut-off.

To obtain the greatest economy in the use of steam it is necessary to supply the cylinder with dry steam and maintain it as dry as possible throughout the stroke. The obtaining of dry steam is now being accomplished for use in locomotive cylinders by superheating the steam—that is, applying additional heat to the steam on its passage between the boiler and the engine.

SUPERHEATED STEAM.

Superheated steam is steam that has a temperature higher than that due to its pressure—that is, its temperature is higher than that of the water in the boiler in which it was generated, while saturated steam has the same temperature as the water from which it was evaporated. For any given pressure saturated steam has a certain constant temperature. At 170 lbs. gauge pressure, for example, the steam always has a temperature of 375° F., and a volume of 2.47 cubic feet per pound.

If heat is added to water in a boiler under a given pressure of steam, it is transmitted to and continues to evaporate water though the steam's temperature will not increase so long as the pressure remains the same. And where heat is abstracted from saturated steam, in its act of doing work in the cylinder of an engine, owing to the cooling influences of surface contact, part of the steam condenses. The amount condensed is almost proportional to the heat given up, and the resulting condensation is inert so far as capacity for further work is concerned.

However, where steam has left a boiler and passed through a heating device, termed a *superheater,* it is separated from the water, and the application of heat will raise its temperature, increase its volume, although pressure will remain the same, and it becomes Superheated Steam. When superheated steam gives up heat, the superheat

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is the first to be given up, and the steam remains steam until all of the superheat has been abstracted. Superheated steam is a poor conductor of heat, while, on the other hand, saturated steam is a good conductor of heat. The poor heat conducting properties of superheated steam have a marked effect on the efficiency of superheater engines, which will become apparent later on.

Superheated steam partakes more of the nature of an ideal, perfect gas than saturated steam, and the farther the process of superheating is carried—that is, the higher the temperature of superheat, the more nearly it approaches the characteristics of a perfect gas. Superheated steam has a greater volume than an equal weight of saturated steam, for steam, like other material substances, expands with increment of temperature. For example, one pound of saturated steam at 170 pounds, gauge pressure, 375° F., superheated 200°, to a temperature of 575°, increases from a volume of 2.47 cubic feet to 3.27 cubic feet at the same pressure.

In addition to the increase of volume, which increases very nearly in proportion to the rise of temperature, the use of superheated steam in locomotives becomes advantageous and effects economy in fuel and water consumption by reason of the further following causes:

(A) Reduction of cylinder condensation.
(B) Low thermal conductivity.
(C) Reduction of back pressure.
(D) Increased hauling capacity.

(A) The reduction of cylinder condensation is the most important economy effected by superheating. When using saturated steam under ordinary working conditions, a large quantity of the steam admitted to the cylinders immediately condenses without doing any mechanical work, the water of condensation being suspended in the steam passing through the cylinder, and this condition is augmented by the good conducting properties of saturated steam. Superheated steam, on the contrary, loses practically none of its capacity as a working agent, and its use reduces the amount of condensation because a lesser quantity is needed to give up a specified amount of heat.

(B) While saturated steam is a good conductor of heat superheated steam is a poor conductor, which is of great value because it reduces the loss caused by cooling in the cylinder.

(C) Back pressure is reduced because of the smaller volume and lesser weight of steam required to do a given amount of work.

(D) The hauling capacity is increased because the mean effective pressure is higher than when using saturated steam.

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PART V

BOILERS

CLASSES AND TYPES, CONSTRUCTION FEATURES, SUPERHEATERS, DRAFT APPLIANCES, SAFETY DEVICES, PARTS AND APPURTENANCES, BOILER POWER DATA, INJECTORS.

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CLASSES AND TYPES.

THE power of a locomotive is limited by its boiler's steaming capacity, which depends on the size of fire grate, the relative heating surface, and the maximum rate of fuel consumption.

Locomotive boilers are designed with a large area of heating surface compared with the amount of water carried, for owing to restrictions of space and weight, they must be very rapid steam generators. Within the limits of these restrictions locomotive boilers are usually constructed as large as possible.

The chief value of a large boiler lies in the fact that it carries such a bulk of hot water that, should the steam pressure tend to fall when the locomotive is being worked to its maximum capacity, the feed can be shut off, temporarily increasing the boiler's generating capacity, owing to the fact that the latent heat of evaporation only has to be supplied.

Locomotive boilers are of the horizontal, internal firebox, multi-fire-tubular kind. Their main parts are firebox, in which the fuel is burned; cylindrical part or barrel, containing the fire tubes; steam dome, and smoke box. There are three classes in general use: *Straight Top, Wagon Top,* and *Extended Wagon Top.* These three classes are divided into types owing to certain modifications, deriving names from the characteristics of their fireboxes. Thus there are the following firebox types: *Belpaire, Radial Stayed, Wootten,* and *Jacobs-Schupert.* All but the Wootten and the Jacobs-Schupert types can be constructed with either narrow or wide fireboxes, though most of the locomotive boilers now being constructed have wide fireboxes.

CONSTRUCTION FEATURES.

Steam pressure inside of a boiler exerts stresses equally in every direction that have a tendency to force the boiler into circular form, if it does not possess that form, and if it does, the pressure has a tendency to sustain the circular form, and therefore all flat surfaces and surfaces not circular or spherical must be braced or stayed. The outside shell of a locomotive boiler including the smoke box in front and the enlarged back end, which forms the outer shell of the firebox, consists of several sheets or courses. The sheets forming the shell, and the firebox sheets also, are fastened together with rivets, making tight seams that withstand the pressure of water and steam. The outer and inner firebox shells are joined at the bottom by the mud ring or foundation ring. Above the mud ring they are joined on sides, back and front by stay bolts and the crown and roof sheets are

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joined with crown bolts (The Jacobs-Schupert type is an exception to this method of staying).

There are several methods of making riveted boiler seams, but the butt joint seam having an efficiency of from 80 to 90 per cent. is the one now almost exclusively employed in the construction of locomotive boilers. The lap seam permits of an eccentric tendency in the pull on the joint that causes a continual bending of the sheet along the calking edge, sometimes under the lap, that seems to set up the right conditions for grooving, and sometimes an unexpected rupture is the result. In the butt joint the pull is central, which removes this cause for grooving. The butt joint generally adopted has a wide inside and a narrow outside cover plate. Sometimes the joint is welded and a cover plate put on in addition, so as not to depend entirely on the weld.

The stay bolts and crown bolts are of several kinds. The *Solid, Hollow, Flexible* and *Sling* are the kinds most generally used. The ordinary stay bolt is screwed through both sheets and its projecting ends are hammered and riveted over. Flexible stay bolts are used to afford some elasticity between the inner and outer firebox sheets, which have different rates or degrees of expansion, causing numerous breakage of stay bolts. Hollow stay bolts are used for admitting air above the fire as well as to more easily discover a broken stay bolt by the escape of steam and water.

SUPERHEATERS.

Superheaters are becoming extensively used on locomotives, and while they are not a part of the boiler proper, they may be considered an adjunct to it, as they materially assist in steam formation. There are two classes of locomotive superheaters, the smoke box and the fire tube.

The smoke box class requires no modification or change in the usual boiler construction, being installed entirely within the locomotive smoke box, and is employed where what is known as low degree superheat, temperature increases from 100 to 150 degrees F., meets requirements. It consists of two drums bolted directly to the steam pipe cone, which is of ordinary construction. Each lower drum communicates with the live steam passage leading to the corresponding cylinder, there being a complete set of drums and tubes on each side of the smoke box. The tubes are expanded into tube plates, thus insuring tight joints. The drums are of cast steel, and are so divided by longitudinal and transverse partitions that the steam passes successively through different groups of tubes while flowing from the dry-pipe to the cylinder. By means of suitably arranged deflecting plates, the waste gases (from which this class receives all its heat) from the

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fire are compelled to circulate among the superheater tubes, and the heat stored in these gases is thus utilized to the best advantage. Sparks and cinders are trapped, and are removed through a conveniently located cinder pocket.

The fire tube class is installed part within the fire tube and part within the smoke box. It is employed when high degree superheat is desired, superheating the steam to total temperatures of from 600 to 650 degrees F. In the usual form of construction, fire tube superheaters consist of small tubes of from 7/8 inch to 1½ inches in diameter, connected to a box or header in the smoke box. One end of the tubes is connected to the compartment of the header into which steam from the dry pipe flows. Steam from the dry pipe flows back through the small tubes, which are located within fire tubes of large diameter, nearly to the firebox and returns to the compartment of the header opening into the steam pipes. In passing through the small tubes the steam takes up heat from the products of combustion passing through the fire tubes.

The flow of heat through the large fire tubes is controlled by dampers hinged or pivoted below the steam header in the smoke box. So long as the throttle is shut these dampers are kept closed by either a counterweight or spring; but as soon as steam is admitted by opening the throttle they are automatically opened simultaneously by means of a piston working in a small steam cylinder. Thus while getting up steam, or whenever the throttle is closed, and the superheater pipes are not cooled by flowing steam, no gases of combustion can pass through the large fire tubes, which prevents the superheating pipes from becoming overheated.

DRAFT APPLIANCES.

As locomotive boilers are comparatively small, artificial or forced draft is necessary in order to burn sufficient coal to supply the cylinders with the requisite amount of steam.

In connection with the term draft it should be understood that motion of gases is produced by a greater pressure at one point over that at another toward which the gases are flowing, and the greater the difference in pressures the greater the velocity of flow. As gases are discontinuous bodies it is clear that there can really be no such motive force as draft, and so the draft appliances of a locomotive fulfil the requisite conditions, that is, produce differences of pressure. A partial vacuum is created in the smoke box and the greater, or atmospheric, pressure on the outside forces its way through the fuel bed and tubes to the smoke box and draft appliances. The cause of motion of the products of combustion is always from pressure.

The parts usually spoken of as draft appliances consist of *Smoke*

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Stack, Deflector Plate, Exhaust Pipe, Exhaust Nozzle, Stack Extension, Lift Pipe, or *Petticoat Pipes,* and *Steam Blower.* These parts are on or in the smoke box.

The smoke stack has two functions to perform: First, to carry off the products of combustion and exhaust steam; second, an appliance, sometimes in connection with a lift pipe, or petticoat pipe, through which the jet of exhaust steam induces a draft. After the exhaust steam leaves the exhaust nozzle its volume expands, filling the smoke stack. The successive puffs of steam filling and moving through the stack, like a piston, induce draft by creating a partial vacuum similar to the action of a pump piston.

The deflector plate is attached to the front tube sheet above top row of tubes projecting at an angle to the tube sheet downward and forward. The lower part is usually made adjustable, permitting it to be raised or lowered whenever necessary to regulate the distribution of draft through the tubes. The air entering fire through back portion of grates passes through top tubes, that entering through middle part of grates passes through middle tubes and that through the front part of grates passes through bottom tubes. The location of stack has a tendency to induce the greatest draft through the upper tubes. This tendency is corrected by the deflector plate, or petticoat pipe, deflecting the gases downward, lengthening their path, which is equivalent to equalizing the differences of pressure over the entire tube sheet, for the longer the path of the gases the greater the frictional resistance. If the fire in front part of firebox burns brighter than in the back it indicates that the draft is too great in lower tubes. This condition is corrected by adjusting the deflector or petticoat pipe to a greater height. If the draft is too severe in upper tubes or back end of firebox the deflector or petticoat pipe should be lowered. The deflector plate or petticoat pipe can be so adjusted as to give equal draft over entire grate area.

The exhaust nozzle regulates the velocity of steam through the stack. It should be of such size as to give sufficient intensity to draft through fire, though not create too much back pressure in the cylinders. A small nozzle creates intense draft through the fire, though causes excessive back pressure in the cylinders, while a large nozzle creates a light draft and relieves the back pressure. The proper size nozzle for any particular locomotive depends largely on conditions, such as quality of coal, the rate of combustion and the volume of exhaust steam. An ideal nozzle would be one large enough to allow the locomotive to steam well with as little back pressure as possible. Reducing back pressure is equivalent to increasing boiler pressure. With the draft through the fire and tubes not so intense the gases of combustion remain in contact with the heating surfaces of the boiler a longer period of time and so give up more of their heat, thus tending toward fuel economy.

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The steam blower is an auxiliary draft appliance for creating a draft when the locomotive is not exhausting. It simply projects a jet or number of jets of steam through the stack, producing a draft very similar to that produced by exhaust steam.

SAFETY DEVICES.

Boilers are provided with safety valves to permit the escape of steam when the pressure rises above a certain limit, known as the "allowed" working pressure. Locomotive boilers are always provided with two or more safety valves so that in the event of one becoming inoperative the other will take care of the pressure. Ordinarily, they are set to lift at about 2½ pounds difference in pressure, the one set at the lowest pressure being set to lift at the allowed working pressure. It lifts first and if the pressure continues to rise the others will lift and discharge an additional volume of steam.

The steam pressure of a boiler is indicated by an instrument known as the steam gauge. Steam gauges all operate on either one of two principles. In one class the pressure of steam acts on diaphragms or corrugated plates. The corrugations give them elasticity, and when pressure is exerted between them they are forced apart. The diaphragm or plate is connected with the gauge pointer by a suitable mechanism so its movement is properly communicated to the pointer which indicates on the scale. In the other class of gauge, the steam acts upon a bent metal tube of a flattened or elliptical cross-section. If a tube of elliptical form be bent in the shape of the letters U or C, and is subjected to the pressure of a fluid on the inside, the force exerted by the pressure will tend to straighten out the tube. And so in the class of gauge using a bent tube one end of the tube is attached rigidly to the frame of the gauge, while the other end, free to move, is connected to the gauge pointer by suitable mechanism to give it its proper movement. The siphon pipe that connects the gauge to the boiler is made long and coiled, and these coils fill with condensed water, which prevents the steam coming in contact with the diaphragm or tubes, the heat of which affects the indications of the gauge.

PARTS AND APPURTENANCES.

The distinguishing features of the several classes of boilers, types of fireboxes, sheets forming their shells, and boiler appurtenances follow:

Straight Top Boiler.—A boiler having a shell of uniform diameter with its top level with top of the outside firebox sheet.

Wagon Top Boiler.—A boiler having outside firebox sheets join the smaller cylindrical part of boiler with a conical or sloping course, usually having the steam dome over the crown sheet, which is supported with crown bars in this class. Becoming obsolete.

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Extended Wagon Top Boiler.—A boiler having the conical sheet further ahead than in the Wagon Top class, with the steam dome located ahead of the firebox so that the crown sheet can be supported with radial stays, obviating the use of the less satisfactory crown bars.

Belpaire Firebox.—A firebox having flat crown and roof sheets, and practically flat inside and outside side-sheets, the upper edges of the side sheets joining crown and roof sheets with curves of short radius. The practically flat inside and outside sheets being parallel permit of straight and direct staying in this type. See Fig. 30, and illustrations of Pennsylvania Railroad 2–8–0 type and Great Northern 2–8–2 type, Part II.

Radial Stayed Firebox.—A firebox having a curved or flat crown sheet that is stayed with stays or crown bolts set on lines that are radii of curvature of the inner and outer sheets. See Fig. 31.

Wootten Firebox.—A very wide firebox having a curved crown and roof sheet of large radius. See Fig. 32, and illustration of Lehigh Valley 4–4–2 type, Part II.

Jacobs-Schupert Firebox.—The Jacobs-Schupert firebox is a new departure in firebox construction. In it the usual side sheets, crown sheet, outside and roof sheets are replaced by a series of semi-elliptic channel-formed sections riveted together with their flanges away from the fire. The inner and outer channel sections are held together by stay sheets interposed between each section, instead of with stay bolts as in ordinary fireboxes, and held securely thereto by the same rivets that fasten these sections together. The stay sheets are partially cut out above the mud ring and they are also perforated throughout the water and steam space above to afford horizontal circulation of water along the sides and over top of the crown sheet, and to permit the free movement of steam above the water. The use of stay bolts is eliminated in all sheets except the throat sheets, and back head and door sheets, which are the only flat sheets in this type. See Fig. 33, and illustration Santa Fe 4–6–2 type, Part II.

Narrow Firebox.—A firebox resting on the frames or extending down between them, having a narrow grate, 42 inches or less in width.

Wide Firebox.—A firebox resting on the frames and extending beyond them at the sides, having a wide grate.

Smoke Box.—The front part of the boiler into which the products of combustion are discharged before being emitted from the stack. See No. 4, Fig. 30.

First Course.—That section of the boiler adjoining the smoke box. Cylindrical in straight top and extended wagon top boilers, and shaped like the frustrum of a cone in some Belpaire boilers. See No. 11, Fig. 30.

Second Course or Dome Sheet.—That section adjoining the first course. If the steam dome is attached to it, it is termed the dome sheet. Made either straight or tapering. See No. 12, Fig. 30.

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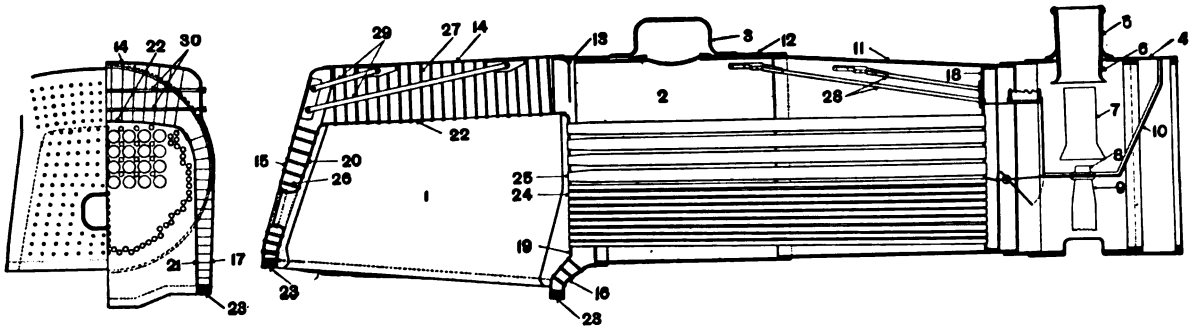

FIG. 30.—Belpaire firebox locomotive boiler.

1. Firebox.
2. Cylindrical part or barrel.
3. Dome.
4. Smoke box.
5. Smoke stack.
6. Stack extension.
7. Lift pipe or petticoat pipe.
8. Exhaust nozzle.
9. Exhaust pipe.
10. Spark arrester netting.
11. First course.
12. Second course or dome sheet.
13. Hip sheet.
14. Roof sheet.
15. Back head.
16. Outside throat sheet.
17. Outside side-sheet.
18. Front tube sheet.
19. Back tube sheet.
20. Door sheet.
21. Inside side-sheet.
22. Crown sheet.
23. Mud ring.
24. Fire tubes.
25. Superheater fire tubes.
26. Staybolts.
27. Crown bolts.
28. Braces, front tube sheet.
29. Braces, back head.
30. Cross stays.

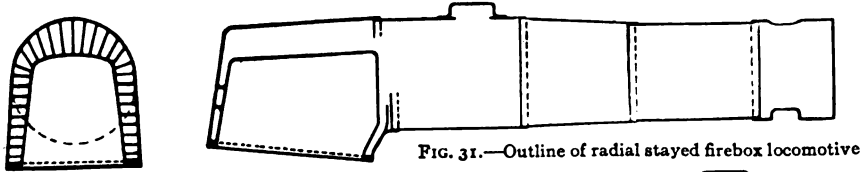

FIG. 31.—Outline of radial stayed firebox locomotive boiler.

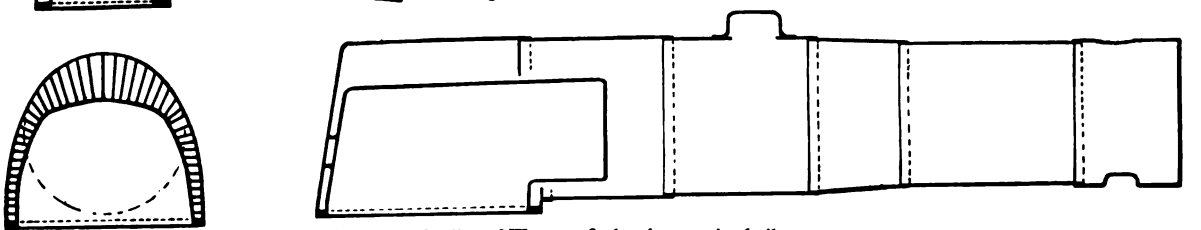

FIG. 32.—Outline of Wootten firebox locomotive boiler.

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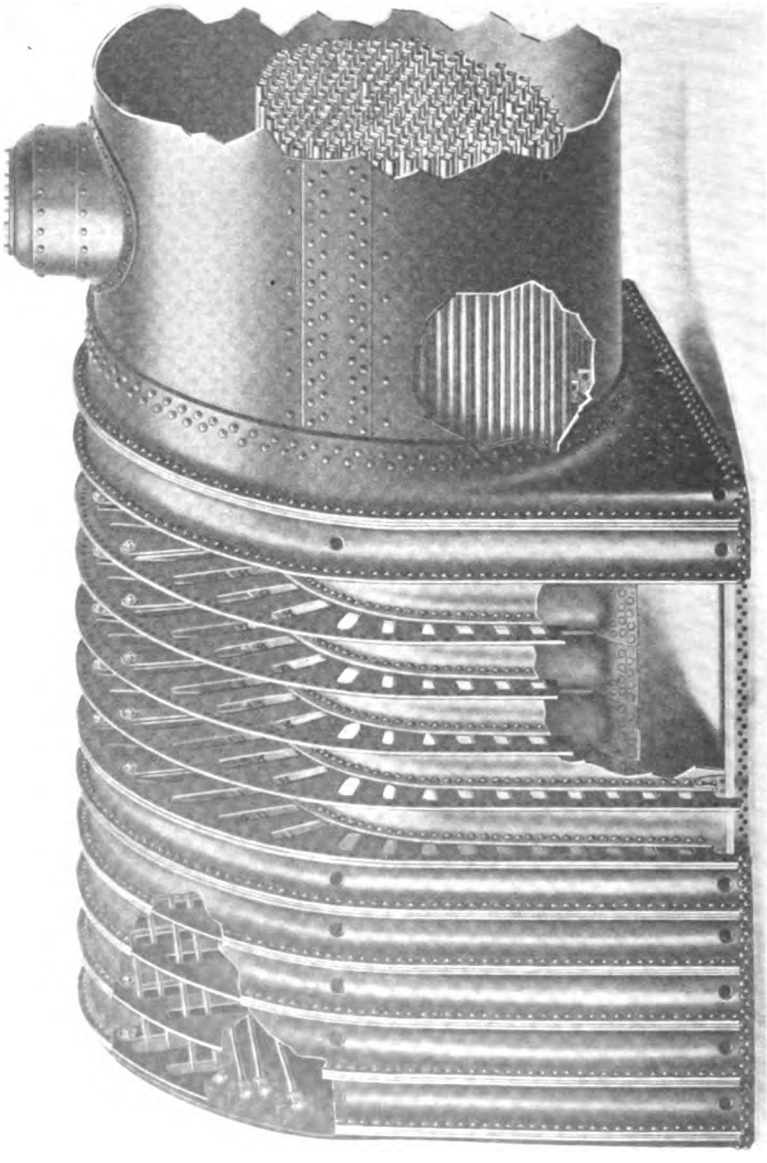

FIG. 33.—Jacobs-Schupert firebox.

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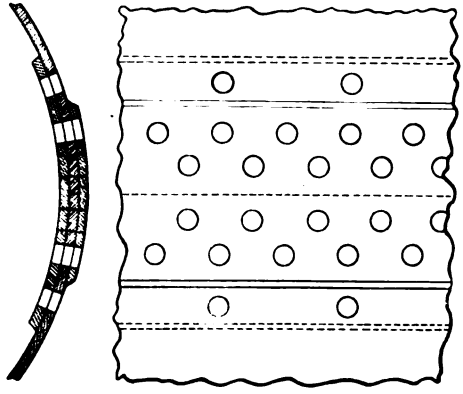

FIG. 34.—Butt joint.

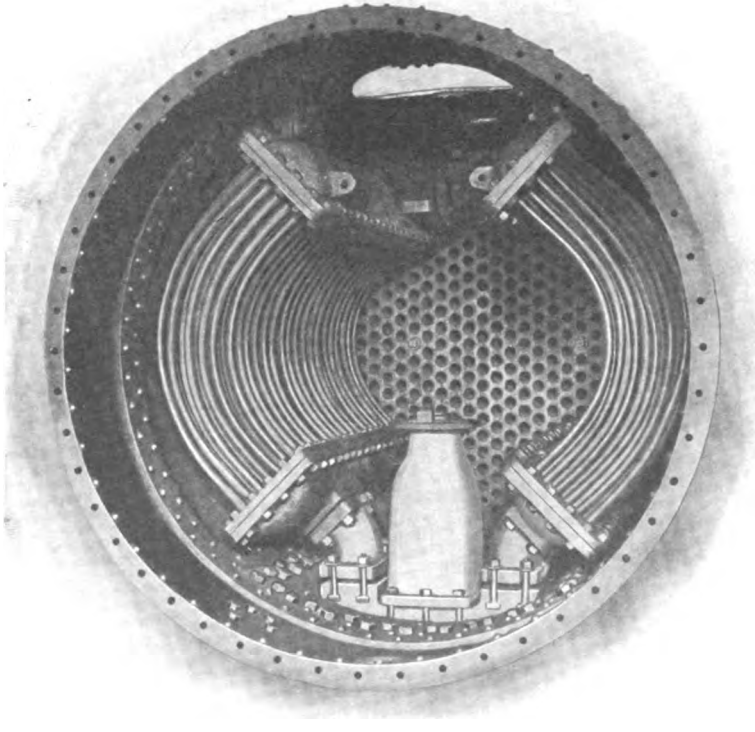

FIG. 35.—Smoke box superheater.

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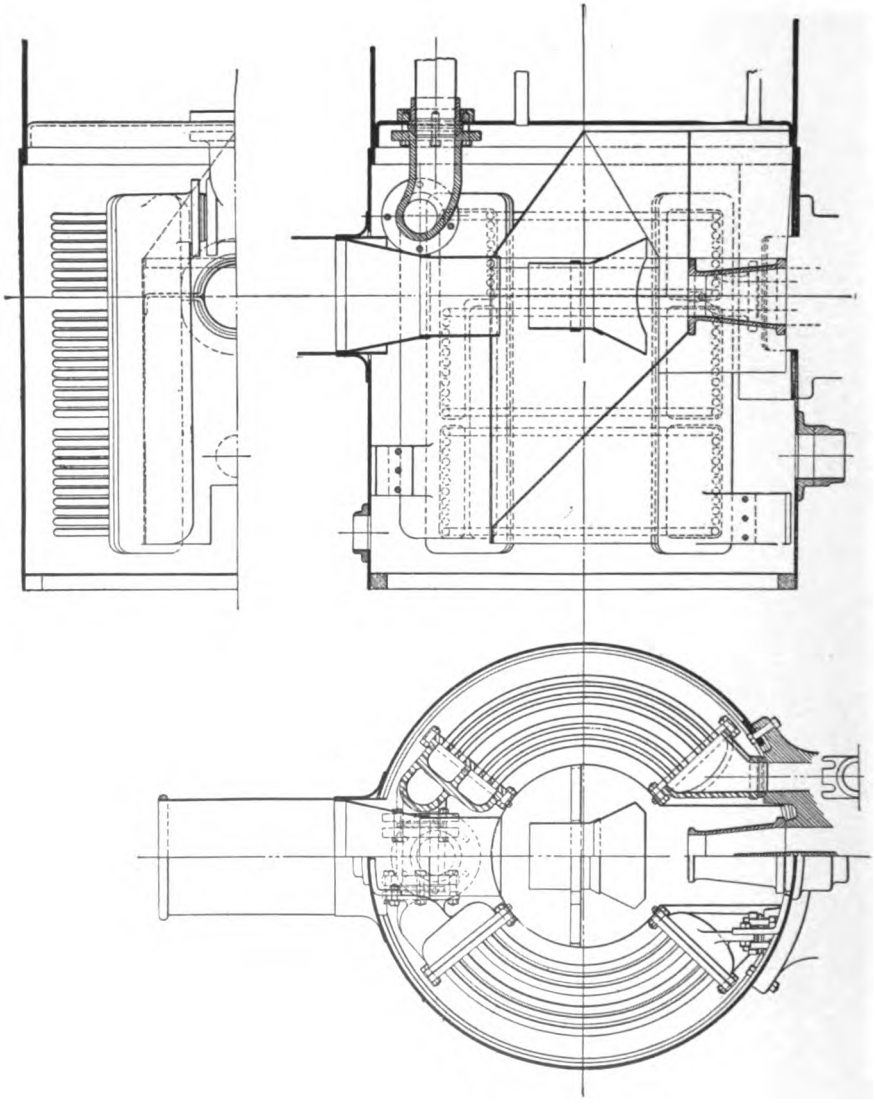

FIG. 36.—Smoke box superheater.

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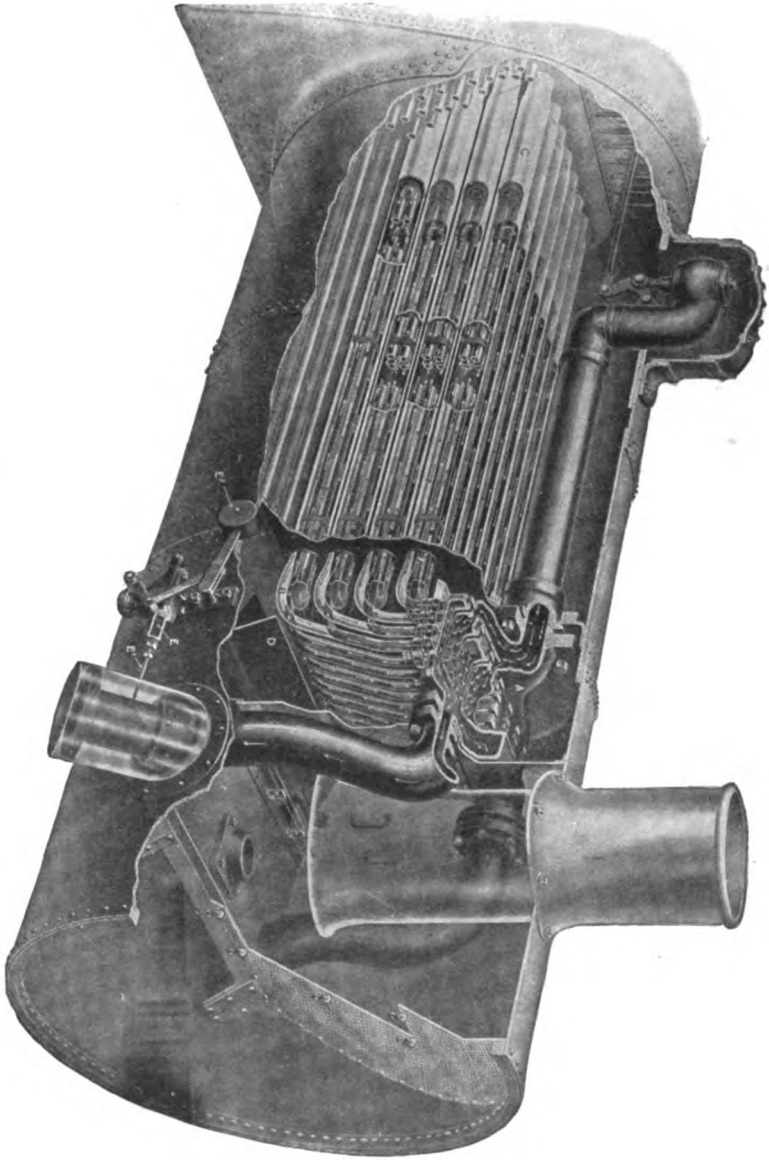

FIG. 37.—Fire tube superheater.

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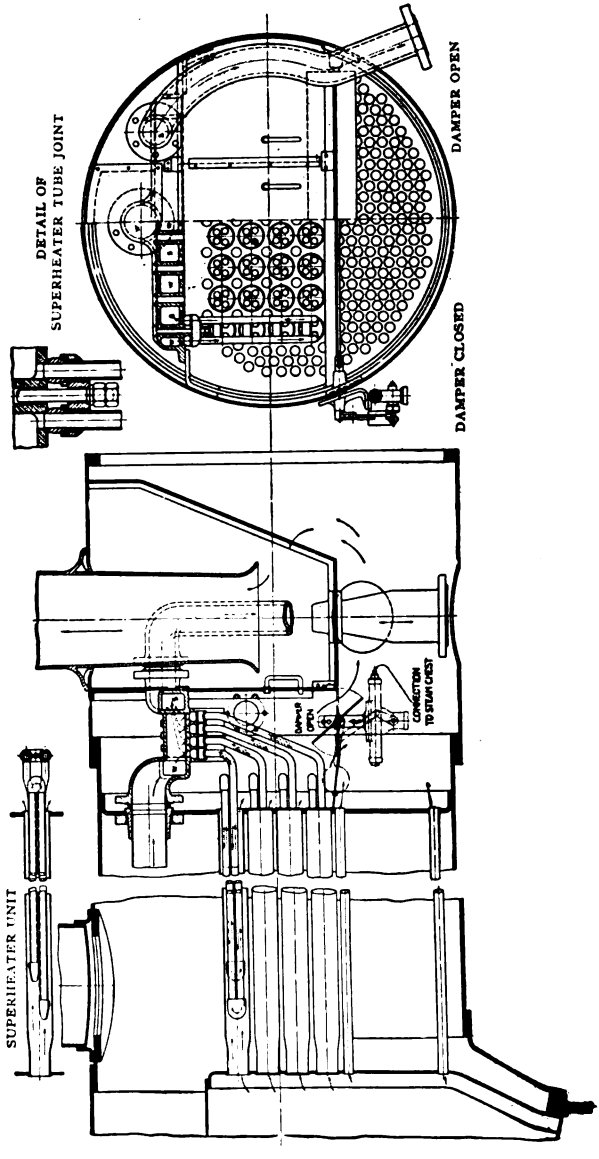

FIG. 38.—Fire tube superheater, top header type.

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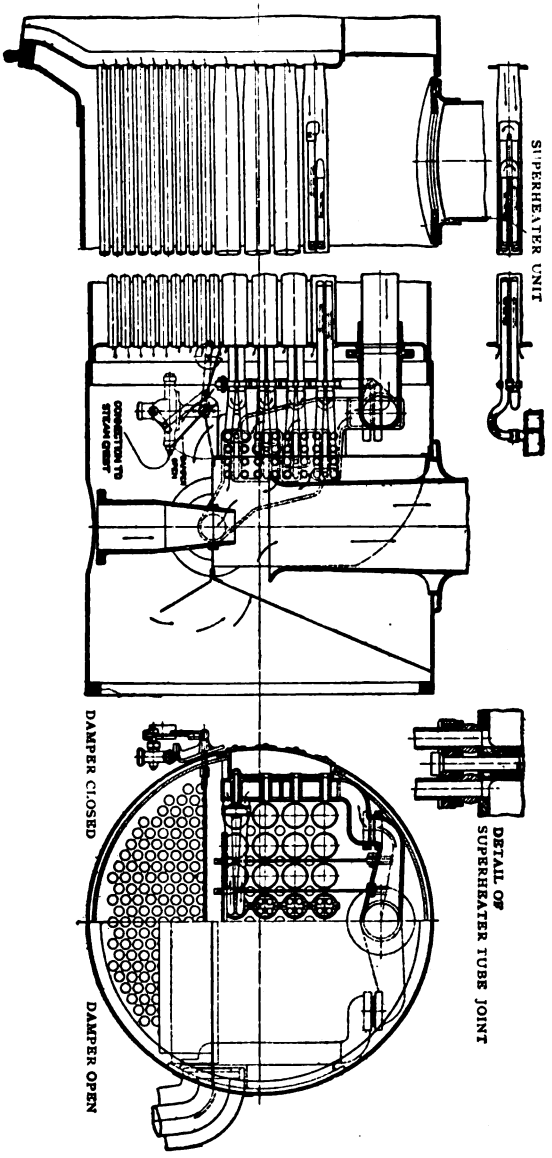

FIG. 39.—Fire tube superheater, side header type.

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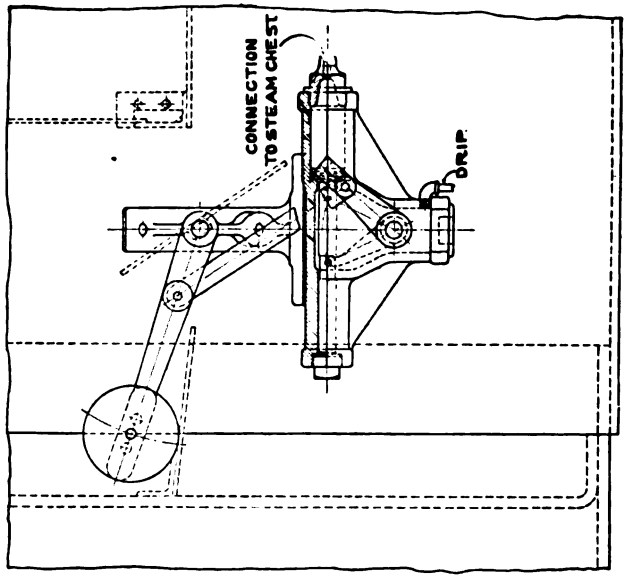

FIG. 41.—Superheater damper cylinder showing counter-weight up, damper open.

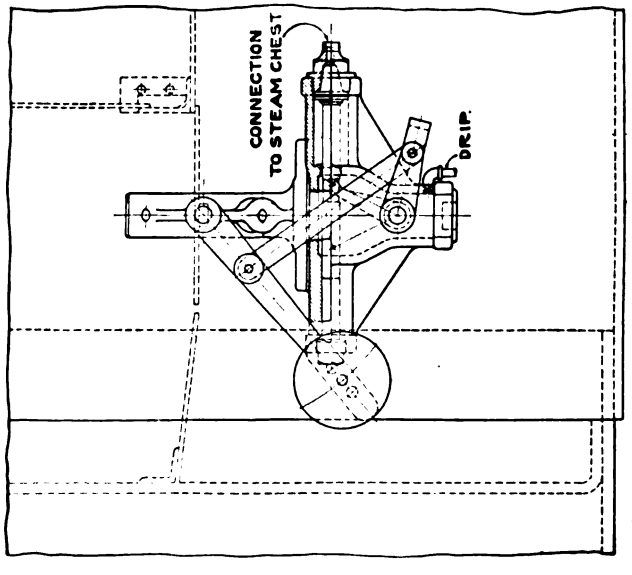

FIG. 40.—Superheater damper cylinder showing counter-weight down, damper closed.

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Dome.—A cylindrical reservoir located on top of the boiler, which permits the storage of steam and provides a space for the throttle valve where it can best get dry steam. See No. 3, Fig. 30.

Outside Firebox Sheet—Roof Sheet.—The outside sheet of firebox end of boiler to which the inside sheets and crown sheet of radial stayed fireboxes are secured by stay bolts and crown bolts. The top sheet of Belpaire fireboxes is termed the roof sheet. See No. 14, Fig. 30.

Hip Sheet.—A sheet at the junction of the boiler shell and outside firebox shell at the top of Belpaire firebox types. See No. 13, Fig. 30.

Back Head.—The sheet forming the back end of the boiler. See No. 15, Fig. 30.

Throat Sheet.—A sheet forming the outside member of the front leg of the firebox, bent or flanged to properly connect with the cylindrical portion of the boiler. See No. 16, Fig. 30.

Inside Throat Sheet.—A sheet forming the front part of firebox in boilers that have back tube sheet set ahead of the front water leg.

Door Sheet.—A sheet forming the back part of the firebox, with the fire door opening cut in it and the edges flanged back joining the back head. See No. 20, Fig. 30.

Crown Sheet.—A sheet directly over the fire and forming the top of the firebox. They are flat in some types and curved in others. See No. 22, Fig. 30.

Tube Sheet.—A sheet forming one end of the boiler, and having holes in which the tubes are inserted. The tube sheet at the smoke box end is termed the front tube sheet and that at the firebox end is called the back tube sheet. See Nos. 18, 19, Fig. 30.

Tubes.—The tubes are pipes ranging in diameters from 1⅞ to 5½ inches, extending through the boiler between the tube sheets, and serve to convey the products of combustion from the firebox as well as provide heating surface. The adhesive properties of the tubes, which are expanded into the holes of the tube sheets, have sufficient holding effect to brace that part of the tube sheets. For tubes see Nos. 24, 25, Fig. 30.

Mud Ring.—An iron or steel bar, shaped to correspond to the bottom plan of the firebox, separating the inside and outside shells of the firebox, and to which the sheets of these shells are riveted. Also called Firebox Ring and Foundation Ring. See No. 23, Fig. 30.

Front Tube Sheet Braces.—Stay rods extending from the front tube sheet to top of the boiler shell, supporting the tube sheet above the tubes. See No. 28, Fig. 30.

Back Head Braces.—Stays extending from the back head to the roof sheet or outside sheet of firebox supporting the back head above the stay bolts. See No. 29, Fig. 30.

Cross or Transverse Stays.—Stay rods extending between the outside sheets of Belpaire fireboxes, bracing the flat surfaces of those sheets above the stay bolts. See No. 30, Fig. 30.

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Riveted Joints.—The *lap joint* is a method of fastening boiler sheets or plates by laying the edge of one sheet over the other and then riveting them. When the edges of the sheets are brought together—butted—but not over-lapped, and strips or welts riveted to one or both sides of each sheet, covering the joint and holding the ends of the sheets together it is termed a *butt joint.* See Fig. 34. for butt joint.

Superheaters.—See Figs. 35 and 36 for cuts of the Baldwin smoke box class of superheater.

See Figs. 37, 38, 39, 40, and 41, for the Locomotive Superheater Company's fire tube class of superheater. In Fig. 37, letter "A" indicates the header; "B," the superheater pipes or units; "C," the superheater fire tubes; "D," the superheater damper; "E," the superheater damper cylinder; "E^1," steam pipe connection between main steam pipe and superheater damper cylinder; "E^2," counterweight, which closes the superheater damper when there is no steam flowing through the superheater units.

BOILER POWER DATA.

Correctly speaking, there is no such thing, in connection with a boiler, as *horse power.* The term horse power has two meanings in engineering: *First, an absolute unit or measure of the rate of work,* that is, of the work done in a certain definite period of time, by a source of energy, as a steam boiler, a waterfall, a current of air or water, or by a prime mover, as a steam-engine, a water-wheel, or a wind-mill. The value of this unit, whenever it can be expressed in foot-pounds of energy, as in the case of steam-engines, water-wheels, and waterfalls, is 33,000 foot-pounds per minute. In the case of boilers, where the work done, the conversion of water into steam, cannot be expressed in foot-pounds of available energy, the usual value given to the term horse power is the evaporation of 30 pounds of water of a temperature of 100° F., into steam at 70 pounds pressure above the atmosphere. Both of these units are arbitrary; the first, 33,000 foot-pounds per minute, first adopted by James Watt, being considered equivalent to the power exerted by a good London draught horse, and the 30 pounds of water evaporated per hour being considered to be the steam requirement per indicated horse power of an average engine.

The second definition of the term horse power *is an approximate measure of the size, capacity, or rating* of a boiler, engine, water-wheel, or other source or conveyor of energy, by which measure it may be described, bought and sold, advertised, etc. No definite value can be given to this measure, which varies largely with local custom or individual opinion of makers and users of machinery. The nearest approach to uniformity which can be arrived at in the term *horse power,* used in this sense, is to say that a boiler, engine, water-wheel,

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or other machine, *rated* at a certain horse power, should be capable of steadily developing that horse power for a long period of time under ordinary conditions of use and practice.

The A. S. M. E. has recommended that in all standard trials boiler horse power shall be 30 pounds of water per hour from a feed-water temperature of 100° F., evaporated into steam at 70 pounds gauge pressure, which shall be considered equal to 34½ units of evaporation —that is, to 34½ pounds of water evaporated from a feed-water temperature of 212° F. into steam at the same temperature. This standard is equal to 33,305 thermal units per hour.

Unit of Evaporation.—It is the custom to reduce results of boiler tests to the common standard of weight of water evaporated by the unit weight of the combustible portion of the fuel, the evaporation being considered to have taken place at mean atmospheric pressure, and at the temperature due to that pressure, the feed-water being also assumed to have been supplied at that temperature. This is, in technical language, said to be the equivalent evaporation from and at the boiling-point at atmospheric pressure or *from and at 212° F.* This unit of evaporation, or one pound of water evaporated from and at 212°, is equivalent to 965.7 British thermal units.

The measure of relative rapidity of steaming of boilers is the number of pounds of water evaporated per hour per square foot of water-heating surface.

The measure of relative rapidity of combustion of fuel in boiler furnaces is the number of pounds of coal burned per hour per square foot of grate surface.

Measurement of Heating Surface.—The usual rule is to consider as heating surface all the surfaces that are surrounded by water on one side and by flame or heated gases on the other, but there is a difference of opinion as to whether tubular heating surface should be figured from the inside or from the outside diameter. For the sake of uniformity, however, it would appear to be the best method to consider all surfaces as heating surfaces which transmit heat from the flame or gases to the water, and to use the external instead of the internal diameter of tubes, for greater convenience in calculating, the external diameter of boiler tubes usually being made in even inches or half inches.

INJECTORS.

The action of the injector is owing to the fact that steam at a given pressure flows from a boiler at much greater velocity than water would flow under the same pressure and conditions, and, further, that a current of any kind, be it steam, air, water, or other fluid matter, owing to friction has a tendency to induce in the same direction a correlated movement of any body with which it may come in contact.

An injector injects or forces water into a boiler from which it

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gets its steam supply, because the water acquires momentum owing to the steam's imparted velocity, overcoming the pressure in the boiler. The steam, in forcing water through an injector into a boiler, gives up its heat and performs actual mechanical work as truly as though it acted on a piston moving a pump plunger with it. The heat of the steam is not lost, excepting that that represents the mechanical equivalent of work performed in forcing water to the boiler, for it is stored in the feed water, raising its temperature.

Locomotive injectors are operated by steam from the locomotive's boiler. Each gallon of water fed to the boiler requires about two cubic feet of steam to operate the injector and owing to the steam's condensing its volume when returned to the boiler is only one-sixth of a cubic foot, and so if the boiler does not generate steam as fast as used by the injector in addition to that used by the engine and other steam-using apparatus about the locomotive, a fall of steam pressure results, which varies with volume of steam space in the boiler and conditions under which the locomotive is operating.

Injectors used on locomotives are of two classes, the *lifting* and the *non-lifting*. The lifting injector is capable of lifting water from a lower level than its own, while the non-lifting must be located lower than the water level. The principal parts of both lifting and non-lifting injectors are a *steam nozzle* from which the steam issues in the form of a jet when the injector is in action; a *combining tube* where the steam and water meet, steam condensed and its energy transmitted to the water; a *delivery tube* in which the water attains its maximum velocity; a *check valve* to prevent flow of water from the boiler when the injector is not in action; *hand operative valves* for the admission of steam and water, and an *overflow valve* that permits circulation of steam through the injector when in the act of priming.

OPERATING INJECTORS.

Engineers taking charge of a locomotive should satisfy themselves that both injectors are in good order, and the best way to keep them in that condition is to operate both—*i.e.*, have each injector perform an equal amount of service.

To prime a lifting injector steam is admitted to the steam nozzle, which forms a current in the direction of the combining tube. This current induces the air in the supply pipe above the water to flow in the same direction, creating a partial vacuum in the supply pipe; the atmospheric pressure on the water supply forces the water up to fill this vacuum, thus causing a constant flow to the injector while it is in action. After an injector is primed its proper action is obtained by increasing the steam supply and closing the overflow valve.

In shutting off an injector the lever should be operated easily, so

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that the steam valve will not be forced suddenly to its seat, resulting in injury to the seat and consequent steam leakage. Steam leakage from the steam valve is the cause of most of the annoyance from hot water in the supply pipe, as the steam condenses and flows into the supply pipe, heating the supply water, preventing the injector from priming. An injector that will not prime owing to hot supply water is known among engineers as being *hot,* though it is the water that is hot and not the injector.

The throttle valve of an injector's steam supply pipe should always be kept wide open when the injector is operating.

In order to maintain a properly working injector the following things are important: The water supply should be unobstructed, which means the strainers should be kept clean, good gaskets maintained in hose couplings, tank valves open full, tight joints in supply pipe and hose, properly packed regulating valve stem, clear and unobstructed water way through check, which should fit tight when seated, and free unobstructed passage way for waste from the overflow.

INJECTOR USED AS HEATER.

When the temperature is below the freezing point it is necessary to heat the water in the tender tank and in an injector not in operation maintain a circulation of steam in the supply pipe and hose, and also delivery pipe when exposed, to prevent freezing. For this purpose the injector is used as a heater.

To convert an injector into a heater: Nearly close the steam supply valve to the injector, shut the overflow valve, draw out the starting lever. This allows steam to flow through the supply pipe and hose to the tender tank and to the delivery pipe. The supply of steam to meet the requirements can be regulated by the steam supply valve.

When an injector is in use as a heater, it is important that free circulation of steam be maintained in supply pipe and hose and delivery pipe, which necessitates having the water regulating valve, tank valve and frost cock on delivery pipe open. If the delivery pipe is not fitted with a frost cock or the frost cock is inoperative, the collar nut on union furthest from the injector should be loosened to allow sufficient steam leakage for circulation.

INJECTOR DISORDERS.

The disorders are of two general characters: *First, failure to prime; second, failure to force water after properly primed.*

Failure to Prime.—Clogged strainer or supply pipe; leaks in the supply pipe; supply pipe becoming filled with hot water owing to a leaky steam valve; partially opened tank valve; collapsed tank hose lining obstructing the water supply; tank lid frozen shut.

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An injector will not prime when the water in the supply pipe is hot, owing to the fact that water boils at a low temperature when the pressure at its surface is reduced, and a partial vacuum cannot be maintained in the supply pipe, as the steam generated gives a pressure on the water in the supply pipe equal to that of the atmospheric pressure on the water in the tank. If the water in the supply pipe becomes hot, close the overflow valve and draw out the starting lever, the steam will then force the water in the supply pipe back into the tank. When the supply pipe is clear, open the overflow and prime the injector, then draw the starting lever all the way out.

When an injector does not receive sufficient supply of water owing to the strainer or supply pipe being obstructed, this condition will be indicated by steam appearing at the overflow or by the delivery water being very hot when the injector is in action. In this case follow the instructions of preceding paragraph, and if not effective uncouple the supply pipe hose and clean the strainer or remove the obstruction.

Air leakage into the supply pipe or tank hose will prevent a vacuum being established.

Failure to Force Water after Primed.—Air leakage into the supply pipe or hose; obstruction in the combining and delivery tubes, such as cotton waste, coal, or any foreign matter, and scale formation on the interior of the tubes; boiler check stuck fast on its seat owing to scale formation or mud; collapsed hose lining; partially opened tank valve, and water supply too hot.

A leaky overflow valve diminishes the capacity of an injector, and if the leak is great enough sufficient air will be drawn in to cause the water supply to break and the injector will fail to operate.

When there is a heavy or continuous discharge from overflow, it will indicate the main check valve is stuck on its seat. Tap the check valve lightly with a soft hammer; if this is not effective, the check valve cap will have to be removed when the engine is not under steam. This also occurs when the main check valve is too small.

Air leakage into the supply pipe or tank hose will be indicated by the appearance of steam at the overflow, intermittent sound in the injector's action and chattering of the overflow valve on its seat.

Obstructions in the injector's tubes or scale formation will necessitate the removal of injector for the purpose of proper cleaning.

If a tender tank becomes air tight above the water level owing to freezing or other causes air cannot enter as fast as the water is withdrawn by the injector. The entrapped air expands as the water is withdrawn, though the pressure exerted by it will diminish, and in a short time the pressure will be insufficient to force water to the injector, resulting in the injector's action ceasing.

For types of injectors, parts, and methods of operating them, see Parts and Appliances, Part X.

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PART VI

LUBRICATION

LUBRICATION AND LUBRICANTS, OIL LUBRICATION, GREASE LUBRICATION, VALVE AND CYLINDER LUBRICATION.

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LUBRICATION AND LUBRICANTS.

LUBRICATION is the means adopted to reduce friction to a minimum, and consists of introducing a substance of low co-efficient of friction between surfaces of sliding, rubbing or rolling parts of moving machinery. High machine efficiency from locomotives, maximum time between making of extensive machinery repairs, with proportionate increase in their mileage and earning capacity, necessitates proper lubrication. To obtain this desirable condition, engineers and firemen should have a fair knowledge of lubricants, the physical condition termed friction, and they should thoroughly understand the operating of lubricating devices applied to locomotives.

It also should be borne in mind that efficient lubrication effects economy in a locomotive's fuel consumption to a greater extent than is generally realized. It requires not only power to overcome added friction of improperly or insufficiently lubricated bearings, slide valves and cylinders, but the amount of steam is increased or the power developed is decreased when slide valves become dry from need of lubricant; for the valve gears are strained so that regularity of steam distribution is interfered with, and to make up for these deficiencies and loss of power owing to excessive friction, the cut-off must be increased, resulting in a consequent increased steam and fuel consumption.

Lubricants attain the desired object by interposing themselves between bearing surfaces, either by gravity or pressure, preventing their coming into direct contact with each other.

Conditions are favorable for lubrication when the bearing surfaces are practically smooth, and a grade of lubricant used having sufficient body, viscosity, that it will not be squeezed out from between the bearings by pressure; or, if used for lubricating valves and cylinders, having a high temperature flash-point so that it will not char or decompose from the heat of steam that it comes in contact with.

For lubricating locomotives it is customary to use two grades of oil and a grease compound. On low temperature bearings, such as driving axle journals, rod pins and valve gears, either a light grade of machinery oil or grease compound is used; while for lubricating valves, cylinders and air pumps, a high temperature flash-point grade of valve oil is used.

Oil cups and oiling devices on the machinery of locomotives are generally simple and easily understood, usually needing very little attention beyond adjusting, an occasional cleaning, and the requisite supply of oil. Grease cups are usually of the plunger type, with either

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spring or screw compression, and besides refilling the screw compressors must be adjusted to meet the requirements of the bearing.

Experience on some roads has demonstrated that screw or spring compression plugs for main and side rod grease cups are not necessary for forcing lubricant to the pins if the proper kind of grease is used, for when the bearings become warm the grease expands and flows to the journal.

OIL LUBRICATION.

Some oil cups are packed with woollen waste instead of having adjustable feeds. In oiling bearings fitted with this type of oil cup no more oil should be used than that absorbed by the packing, as that not absorbed is superfluous, for it will drop off the journal or bearing to the ground and will be wasted.

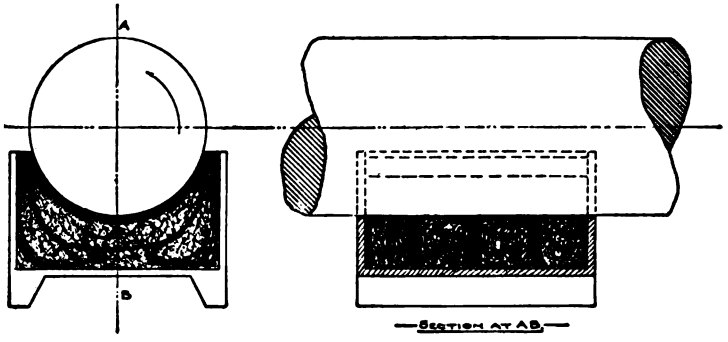

FIG. 42.—Driving box cellar; arrangement of packing.

In this type of oil cup the packing is sometimes covered with a thin covering of hair for the purpose of filtering oil. The hair and packing should both be removed at intervals of about 30 days, cleaned and replaced.

Piston rods and valve stems are usually lubricated with machinery oil, though if sufficient valve oil can be obtained it is good practice to use it for this purpose, as machinery oils contain substances that are deposited in the oil cups, clogging them owing to the action of heat.

In the application of engine oil, intelligent and economical results cannot be obtained unless cups are kept clean, feeds maintained in good condition, and cups, equipped with adjustable feed, are closed when delays occur on the road and on arrival at terminals.

When oiling, care should be exercised not to over-fill oil cups or

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holes, and when oiling bottom guides the oil should be poured crosswise, to permit of the crosshead distributing it over the entire surface.

Driving or engine truck box cellars, of journals lubricated with machinery oil, should be packed with woolen waste as shown in Fig. 42. The packing should be placed in cellars moderately firm in order to prevent settling away from journals, which would occur in a short time, owing to the jarring effect of the moving engine. Locomotive cellars should be examined after every day's run or trip to ascertain that they are in proper condition, and that packing is in contact with the journals.

The tops of driving and engine truck boxes, of oil lubricated journals, should be packed with cotton waste, and the top surfaces kept a

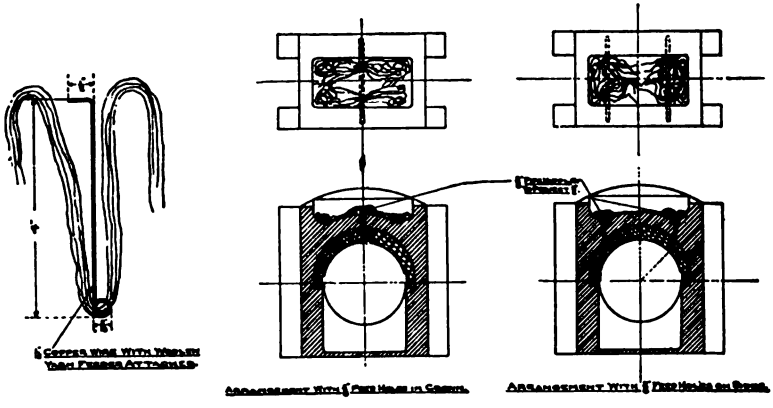

FIG. 43.—Arrangement of wick feeders for top of driving boxes.

little below the tops of boxes so as to have room to hold and prevent escape of oil placed there. It is bad practice when oiling to disturb the packing on top of driving and engine truck boxes with the spout of oil can. The packing is put on top of boxes to keep dust and grit out of oil holes and also to give gradual lubrication from the top. If the packing is disturbed it permits dust and grit to work into oil holes on to bearings, cutting journals and causing them to heat, and the oil will also feed away too rapidly.

If driving boxes are lubricated by wick feeders, made of woollen yarn or cotton wicking, the feeders should be attached to a copper wire to hold them in place in oil holes as shown in Fig. 43. The feeders should be removed at intervals of about 30 days, cleaned and replaced.

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Oil cans on locomotives should be kept in such a location that oil *cannot be heated to a temperature above sixty* (60) *or seventy* (70) *degrees*, for if heated to a high temperature the lubricating properties of machinery oil are impaired, and as heating oil makes it thin it will run off bearing surfaces before it can be of use. However, in emergency cases when necessary to thin oil quickly by heating, it can be done by placing the hand-oiler can in a bucket of hot water drawn from the sprinkler hose. It should never be done by placing the oil can in the firebox. Oil cans should be kept in good condition.

GREASE LUBRICATION.

As was previously said in this part, grease cups are usually of the plunger type.

To adjust the screw feed type the plunger should be screwed down till a slight resistance is felt or until the grease bears on the journal. This should be sufficient for a trip or day's run. Bearings lubricated with grease properly run much warmer than if lubricated with oil, and so if the grease is brought just to the journal while cold, when the bearing becomes comparatively warm the grease expands, owing to heat imparted to it, and flows to the journal.

In spring compressor grease cups the feed is regulated by tension of spring and no adjusting is required. With grease cups without compression plungers all that is required is to fill the cup with grease compound and replace the cup lid.

The practice of screwing plungers till grease oozes out from between brasses and collars is very wasteful.

One type of driving journal lubricating device using grease compound consists of a perforated plate that fits against the lower portion of the journal, preventing the too rapid wearing away of the grease, the grease being forced to the journal through this perforated plate by tension of a spring, located under the follower plate.

When the device does not feed owing to some disorder or the perforated plate becomes clogged, the journal cuts away the bearing rapidly, sometimes without developing a hot journal, though this condition may be indicated by the appearance of small particles of brass cuttings deposited on the driving wheel hub.

Devices used for lubricating driving journals with grease compound usually have two indicator rods attached to the follower plate extending through and below the bottom of the cellar. These indicator rods have notches cut in them that serve the purpose of indicating when the device needs refilling and also whether the grease is wearing uniformly.

Engineers should examine the indicators after each trip or day's run, and when they indicate the device needs refilling or the grease

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is not wearing uniformly, they should make the proper report at engine terminal.

Engineers should oil driving box shoes, hub faces, and wedges on locomotives equipped with grease lubricating devices.

Some locomotives have cross-head pins lubricated with grease. A cross-head pin grease lubricator consists of a hole in the center of the pin threaded to receive a bolt of about one inch diameter. From this hole several small holes lead to the bearing surface of the pin and grease is inserted and the bolt used for a plunger in the usual manner.

VALVE AND CYLINDER LUBRICATION.

The sight feed or cylinder lubricator is a device for supplying oil to the cylinders, steam-chest, and moving parts of machinery surrounded by steam. Its principle is that water being heavier than oil displaces oil in the reservoir, causing it to flow upward in drops through the sight feed glasses to the oil pipes and conducted by them to the steam chests.

The principal parts of a sight feed lubricator are: *Oil reservoir,* with its *filling cup* and *drain cock; condenser, water valve* and *water pipe; oil tubes; regulating valves; sight feed glasses; equalizing tubes,* and *chokes.*

These several parts perform functions as follows: Steam admitted to the condenser condenses, and the water of condensation controlled by the water valve flows to the bottom of the oil reservoir through the water pipe. The water displaces the oil and it flows from the top part of the oil reservoir downward through the oil tubes to the regulating valves and then upward through the sight feed passages to the oil pipes.

The equalizing pipes and chokes are for the purpose of maintaining equal pressure between lubricator and steam chest when the locomotive is using steam. With the sudden, varying steam pressures that occur in locomotive steam chests it is essential to steady working of a lubricator that equal pressures be maintained on both the oil reservoir and oil pipe sides of the feed valves. As the oil reservoir is under boiler pressure, it is, therefore, necessary to have boiler pressure in the oil pipes. This is accomplished by the equalizing tubes conveying steam from the lubricator to the oil pipes. These tubes are comparatively small, and in order to maintain boiler pressure in the oil pipes and also prevent an excessive amount of steam flowing to the steam chest, when pressure in the steam chest is less than boiler pressure, choked openings are placed in the oil pipes, usually at or near the steam chest.

When a lubricator is in operation the pressure in the oil reservoir is equal to boiler pressure plus the weight of water in the condenser,

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and the condenser, equalizing tubes, sight feed passages, and oil pipes are under boiler pressure only. Therefore water from the condenser under pressure of a practically constant head enters the oil reservoir, displaces the oil, and forces it through the sight feed passages to the oil pipes.

Valve oil only should be used in sight feed lubricators. The practice of mixing engine or signal oil with valve oil is wrong, as signal oil has practically no lubricating properties and engine oil has only a small percentage of those contained in valve oil. Besides, the flash point of engine and signal oil is lower than the temperature of high pressure steam and when they come in contact with steam they are charred, their lubricating properties destroyed, and the charred sediment clogs up lubricator, feed valves and oil pipes.

LUBRICATOR DISORDERS.

Decrease in Rate of Feed.—A decrease in the rate of feed may be due to any one of these causes:

First: Lack of condensation resulting from throttling the boiler or steam valve contrary to "Instructions for Operation."

To correct: Keep both valves wide open while lubricator is in operation.

Second: Impurities carried over into the condenser of lubricator from boiler and passing down the water tube will gradually accumulate and reduce the size of water passage, decreasing the amount of water admitted to oil reservoir, thus displacing a lesser amount of oil and decreasing rate of feed.

To correct: Close all feeds and water valve. Open drain cock and allow about half a pint of water to drain off. Close drain cock and open water valve quickly. The condenser pressure will then force this sediment into the bottom of the lubricator, where it should be allowed to remain until the lubricator has fed empty of oil. It can then be blown out in the usual manner. If this sediment is allowed to remain in the water passage too long it may solidify so that it cannot be removed by blowing out, in which case it should be reported so that the obstruction may be bored or cleaned out by a wire.

Irregularity in Rate of Feed.—Irregularity or fluctuation in rate of feed occurs only in feeds to valves and cylinders and is invariably owing to enlarged choke openings.

To correct: Examine the choke openings and if they have become enlarged beyond the limit required by the particular type of lubricator in use, have them replaced with chokes of proper diameter.

Irregular Feed to Air Pumps.—If feed to air pump or pumps stops and the oil passages are clean it is an indication that the choke in air pump oil pipe connection is clogged.

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To correct: Clean choke thoroughly and replace. If air pump feed is spasmodic it shows the choke has been removed.

Increase in Rate of Feed.—Where railroads pass through alkali, salt water, or oil well regions, the water supply becomes impregnated with saline matter. This is carried over into the feed chamber. As the percentage of saline matter increases it in turn increases the buoyancy of the water, thereby exerting a greater influence on the drop of oil forming on the end of feed nozzle, with the result that as percentage increases the drop becomes smaller and rate of feed faster.

To correct: Close feeds. Drain all sight feed chambers. Allow time for condensation; start the feeds, and the oil drops will be normal.

Loose Oil Tube.—If after a lubricator has been filled or refilled and in operation for a time, it ceases to feed, it is an indication that oil tube or tubes have been loosened.

Loss of Oil.—When lubricator is in operation, loss of oil from reservoir may result from irregular feeding due to a worn choke, a deposit at end of the feed nozzle, which would enlarge the drop, or, a large percentage of saline matter in the water in sight feed chambers will force the oil away from the nozzle in a fine stream not easily visible. Or, again, it may be caused by a leak from the oil reservoir to condenser, or oil passages above the sight feed chamber through which oil may escape without passing through feed nozzle. In shutting off lubricator closing the steam valve results in immediate decrease of pressure in condenser, equalizing tubes, sight feed chambers, and tallow pipes, and pressure within the reservoir (boiler plus hydrostatic) will equalize itself with pressure without through any exit from reservoir remaining open, and in so doing carry oil with it; hence the importance of closing feed and water valves before shutting off steam valve and keeping these valves clean and in condition to close properly.

If valves seat perfectly and oil continues to escape, look for loose feed nozzle or sand hole.

Difficulty in Filling.—If after water and feed valves have been closed oil is blown from the reservoir while being filled it is an indication of cut steam or water valve stem or seat; or, very rarely, a leak between oil reservoir and oil passages caused by sand hole or crack. If water valve leaks filling will be accompanied by a gurgling sound, but if this sound is lacking, attention should be given to feed valve stems. If water valve and feed valves are found to be tight the lubricator should be tested for leak between oil reservoir and oil passage.

If lubricator feeds properly when locomotive is standing, but the feeds are retarded when steam is admitted to the cylinders, it indicates that the lubricator is not getting a sufficient supply of steam, owing either to a contracted steam supply pipe or the steam valve not fully opened.

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If a feed valve becomes clogged it can be cleaned by closing all feed valves but the one clogged; close water valve, and open drain cock. Steam will then flow from the equalizing tube in opposite direction through feed valve, forcing the obstruction into the oil reservoir and out through the drain cock, after which the drain cock should be closed. The feed valve should then be closed until sight feed chamber fills with water. As soon as drain cock is closed the water valve should be opened and the other feeds may be started.

If a choke becomes clogged it can be cleaned out by closing the steam valve, opening locomotive's throttle. The steam pressure from steam chest will force the obstruction back into the oil pipe and from there to the sight feed chamber.

NOTES ON OPERATING LUBRICATORS.

Impurities are usually present in the oil and water passing through a lubricator, and as circulation in water tube, oil reservoir and oil passages is necessarily slow, when the lubricator is in operation sediment is liable to collect at certain points and if allowed to accumulate will interfere with the satisfactory working of the device. These passages must be frequently blown out and kept free from sediment or deposit that will obstruct the flow of oil or the proper seating of valves.

A small piece of soap put into the oil reservoir about once a week will keep walls, passages and glasses clean, if, after oil has been fed out, feed is allowed to continue so that soapy water will be forced through the sight feed chambers. Lye should not be used for this purpose, as it impairs the lubricating value of the oil. After using soap blow out the lubricator with steam.

To fill or refill a lubricator: Close feed valves, water valve and steam valve. Open drain cock. After reservoir is drained remove filler plug, close drain cock, and fill with clean, strained valve oil.

Fill reservoir full; if there is not sufficient valve oil, use water to supply the deficiency. This will enable the immediate starting of the feeds, obviating the necessity of waiting for steam to condense and fill the partly filled lubricator. It should be noted that the sight feed chambers are filled with water before adjusting feeds.

After refilling the lubricator the condenser or water valve should be opened immediately, as when the oil in the oil reservoir becomes heated it expands, and damage to the lubricator may result if this practice is not followed. Both the steam and condensing valves should be fully opened when the lubricator is in operation.

Oil should not be allowed to escape from the drain cock when draining the lubricator preparatory to refilling, nor should the rate of

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feeding be increased when nearing the end of day's run or trip for the purpose of draining lubricator of oil.

To adjust feeds care should be taken to see that each cylinder of a simple locomotive is getting the same number of drops or equal quantities of oil. The number of drops will depend on the conditions of service, varying from seven to fifteen per minute on heavy locomotives in fast passenger service, to three per minute in shifting service.

To adjust on compound locomotives more oil should be fed to high pressure cylinders than to low when locomotive is using steam, but when drifting this should be reversed and more should be fed to low pressure cylinders. When using steam, feed two-thirds of oil to high pressure cylinders and one-third to low. And when locomotive is drifting feed two-thirds to low pressure cylinders and one-third to high.

The reason for feeding more oil to high pressure cylinders when using steam is because the steam pressure is higher and friction greater in the high pressure cylinders than the low, necessitating their thorough lubrication, and besides most of the oil fed to the high pressure cylinders passes from them with the steam to the low and assists in their lubrication. On the other hand, when drifting more oil is required in the low pressure cylinders than the high, for they are larger, having much more surface that requires lubricating, and also as little or no oil is received from the high pressure cylinders when drifting.

For types and parts of lubricators see Lubricators, Parts and Appliances, Part X.

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PART VII

CYLINDERS, VALVES AND VALVE GEARS

CYLINDERS AND VALVES, VALVE GEAR AND VALVE MOTION, TYPES OF VALVE GEARS.

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CYLINDERS AND VALVES.

THE cylinders of a locomotive are where part of the steam s heat energy is transformed into mechanical work, which appears in the rotating of the driving wheels. The steam's distribution is accomplished by the *valves,* located in the steam chests or valve chambers, admitting steam to and exhausting it from the cylinders. *Valve gears* are the mechanism that transmit motion to the valves, receiving their initial motion from eccentrics or cranks actuated by the turning of the driving wheels, supplemented in some types of gears by a motion from the cross-head. *Valve motion,* often erroneously applied to the gear, refers to various regular motions of the gear but more specifically to movements and functions of the valve during a cycle of the piston.

The steam generated in the boiler in its passage to the cylinders is controlled by the *throttle valve,* which is located in the steam dome. The pipe or pipes for the conductance of the steam from the throttle valve to the cylinders are of two kinds, depending on type of locomotive. They may be arranged either internally or externally, or both, in relation to the boiler. On simple locomotives of ordinary type with internal arrangement the steam entering the *throttle valve* passes through *throttle chamber, upright pipe,* a horizontal pipe termed the *dry pipe,* the *tee head,* which is located in the smoke box and joins the dry pipe where it passes through the front tube sheet. On non-superheater locomotives the steam continues from the tee head through the steam pipe or pipes to the cylinder saddle passages and by them conducted to the steam chests or valve chambers; while on superheater locomotives the steam after leaving the tee head passes through the superheater before being delivered to the steam chests or valve chambers.

Some articulated compound and a few special types of locomotives have externally arranged steam pipes for conducting steam from the throttle valve to the steam chests or valve chambers.

Throttle valves are of several different types, though generally of similar construction. They usually consist of double-faced circular valves, somewhat in the shape of a spool, the upper face being a little larger than the lower, and seating on corresponding circular seats of the throttle chamber. The object of the double-face is so that the pressure on the bottom face of the valve will be nearly equal to that on the top, making what is termed a balanced throttle valve, so that it may be opened easily, for if all the pressure were on top of the valve it would be impracticable to open it. As the area of the upper face of the valve is greater than the lower there is also a tendency

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for the throttle valve to automatically close in case of accidental disconnection of the throttle rigging.

All locomotives have two or more cylinders, depending upon the class of locomotive. The cylinders are cast of iron or steel, bored out smooth and parallel and fitted with pistons, which move forward and back in the cylinders, and by means of suitable mechanical connections impart rotative movement to the driving wheels.

The piston consists of a head or disk making an easy fit in the bore of the cylinder. It is attached to the end of the piston rod, which connects with the cross-head. Pistons for locomotive cylinders are of two kinds: *solid,* and *built-up.* The solid piston is simply a cast iron disk secured to the end of the piston rod. The built-up piston consists of a central piece to which is attached an outer cast iron ring turned up for proper fitting in the cylinder bore. The periphery of both the solid piston and ring of the built-up piston contain two or more grooves into which are fitted cast iron packing rings, which make a steam-tight joint between the piston and the wall of the cylinder. The packing rings are made of a greater diameter than that of the cylinder, a piece being cut out of the ring so that it may be compressed when applied, elasticity expanding the ring so as to make a steam-tight fit in the cylinder.

When cylinders become so worn that the packing rings will not make a steam-tight joint they are rebored, which increases their diameter, making it necessary to replace the pistons with larger ones. Repeatedly reboring would eventually make the cylinder walls too thin to withstand the pressure of steam, and so before this point is reached the usual practice is to bush them. A bushing is simply a cast iron tube turned up to a fit and forced into the bore of a cylinder, and the bushing bored out to the original cylinder diameter.

The cylinder is closed at each end by the cylinder head, secured by stud bolts. The back cylinder head has cast in with it the stuffing box through which the piston rod passes, and which contains the piston rod packing. The front cylinder head is usually solid or plain excepting on locomotives having extended piston rods. On some large locomotives the piston has an extended piston rod which passes through a stuffing box in the front cylinder head and is carried on a bearing in the stuffing box, which has a tendency to keep the piston's movement in the cylinder central, preventing excessive wear of pistons, packing rings and bottom of cylinder.

The piston rod packing, usually metallic, contained in the stuffing box or gland is for the purpose of preventing the escape of steam that would otherwise leak around the piston rod. There are several brands of metallic piston rod packing, though nearly all are of the same general form, consisting of metallic rings of soft composition, such as lead, tin, etc., in proper proportions. These metallic rings

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fit into a conical cup, called the vibrating cup, and are held in place by a helical spring, one end of which bears against the cylinder head and the other against the follower ring, which in turn bears on the metallic packing rings surrounding the piston rod. The vibrating cup makes a joint against a ring, termed the joint ring, which has a flat surface bearing on the vibrating cup and a rounded surface where it bears against the packing gland, thus allowing the piston rod to vibrate and carry the vibrating cup with it, while at the same time it prevents the escape of steam. The packing gland is usually made of cast iron, slipped over the piston rod and attached to the stuffing box by two or more studs.

All cylinders have cocks fitted in each end, termed *cylinder cocks*, for the purpose of draining them of water of condensation. Some are fitted with a cock or cocks in line with and operated by the same mechanism that operates the cylinder cocks, which are for the purpose of draining the steam passages of condensation, preventing it being carried along with the steam into the cylinders.

In tracing the flow of steam from the boiler to the cylinders, it was stated that the steam was delivered in the steam chests or valve chambers. The steam chest is used in connection with a D-slide valve, and consists of a rectangular cast iron box enclosing the valve, steam ports and the valve seat. It is located on top of the cylinder, surrounded by studs screwed into the cylinder casting, by means of which the steam chest cover is bolted down on the chest, securing it to the cylinder. Provision against leakage of steam at the joints is made by means of a copper gasket placed between the steam chest and cylinder casting, and between the top of steam chest and steam chest cover.

Valve chambers are used instead of steam chests in connection with piston valves, performing the same functions. The valve chamber is combined with the cylinder casting proper instead of being bolted on as is the steam chest. Valve chambers always contain a bushing in which the valve works. The bushing contains ports, which are bridged to prevent the piston valve packing rings from catching in the ports. Steam chests and valve chamber heads have stuffing boxes cast in them through which the valve stem (also valve stem extension to piston valves) passes, containing packing for preventing the leakage of steam around the valve stem.

The valves that controls steam distribution in the cylinders are so constructed as to move over ports so situated that steam will be admitted to one end of a cylinder at the same time it is being exhausted from the other end. They must be so constructed as to be capable of fulfilling three conditions: First, admit steam to only one end of the cylinder at one time; second, permit the steam to escape from one end of the cylinder, at least as soon as it is admitted to the other

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end; third, cover the steam ports so as not to allow steam to escape from the steam chest into the exhaust port.

There are two types of valves in general use on locomotives for admitting steam to and exhausting it from the cylinder, the *Slide Valve* and the *Piston Valve* (see Figs. 44 and 45).

The Richardson Balanced Valve, or some modification of it, is the type of slide valve in general use on American locomotives. The balancing of this type is obtained by four rectangular bars fitted into

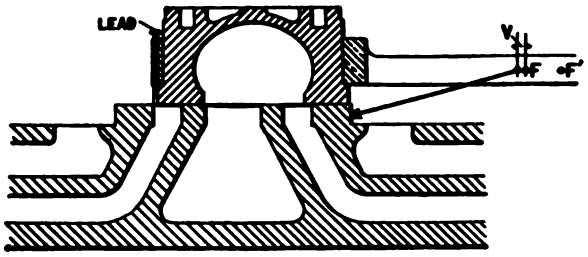

FIG. 44.—Slide valve.

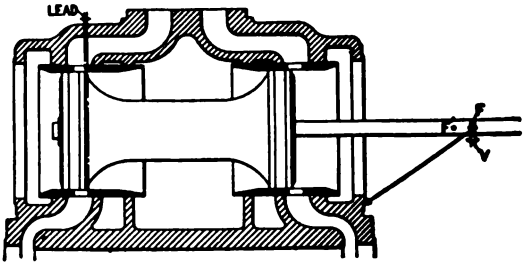

FIG. 45.—Piston valve.

grooves in the top of valve. These bars are lightly held against the pressure plate by semi-elliptic springs; when steam is admitted to the chest pressure acts upon the bars holding them firmly against the pressure plate and also pressing them closely against the inside of their respective grooves, forming a steam-tight joint between valve and balance plate that excludes steam pressure from the area of valve within the bars. In designing the valve the area outside the bars is made greater than the area exposed to greatest pressure under the valve at any time, so that the valve will always be held to its seat.

The piston valve is rapidly coming into general use since the adoption of outside valve gear. It consists of a spool-shaped casting

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of iron or steel, fitting neatly in the valve chamber bushing, where it performs the same functions as the slide valve. Piston valves are usually made with disks or short cylindrical pieces secured to each end fitted with metal packing rings termed snap rings, which form a steam-tight fit in the bushing of the valve chamber. These packing rings are usually made the same diameter as the valve bushing, for if they were made larger and compressed when applied to the valve, it would cause too much friction when locomotives are drifting.

Piston valves are of two types: *Outside admission,* and *inside admission.* Inside admission piston valves are hollow so that when one end opens the exhaust port, part of the exhaust steam can pass through the valve to its opposite end, equalizing the pressure at each end of the valve, producing a perfect balance. If the valve were not made hollow each time the port opened to exhaust there would be exhaust pressure against one end of the valve and atmospheric pressure against the other, which would cause the valve to kick or jerk. By making piston valve inside admission the live steam ports are not so directly exposed to the cooling action of the atmosphere, preventing some condensation. There is also less trouble in keeping the valve stems packed, as the packing is exposed only to the pressure and heat of exhaust steam.

Slide valves are surrounded by the *valve yoke,* of which the valve stem forms a part, the valve stem being forged onto the back of the yoke and extends out through the steam chest, connecting with the valve rod. Piston valves do not require a yoke, the valve stem passing through the center of the valve, being held in place by a nut on the front part.

VALVE GEAR AND VALVE MOTION.

The following notes and definitions explain the various phrases and technical terms relating to valve gear and valve motion, such as lead, cut-off, expansion, etc.

A locomotive is said to be on the *center* when center of main crank pin is on an imaginary horizontal line drawn through the cross-head wrist-pin and the center of the main axle. There are two centers, *forward center* and *back center.* Midway or 90 degrees from the centers are points termed quarters, *top quarter* and *bottom quarter.*

The terms *direct motion* and *indirect motion* refer to relative motions of the valves and the eccentric rods. On direct motion locomotives the valve moves the same direction as the eccentric rod, while on indirect locomotives owing to the reversal of motion by the rocker arm the valve moves in an opposite direction to that of the eccentric rod.

An *outside admission* valve is a valve that admits steam to the

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steam ports by the outside edges or ends of the valve, and exhausts steam by the inside edges. An outside admission valve may be either of the *D-slide* pattern or the round, *piston* type. An *inside admission* valve performs its functions exactly opposite to that of the outside admission valve, and all inside admission valves in common use are of the piston type.

The *reverse lever* is used not only for controlling the direction of motion of the locomotive but also to regulate the point of cut-off. It is said to be in *full forward gear* when at the front end of quadrant, *full backward gear* when at back end, and *mid-gear* when half way between these points. When the reverse lever is in either end of the quadrant the valve has its full travel and admits steam to the cylinder during almost the full stroke of the piston.

Admission.—The admitting of steam to one end of a cylinder. If the valve has no lead, admission begins the instant the piston begins its stroke and continues to the point of cut-off.

Angular Advance.—If a valve has neither lap nor lead the eccentric center would be set at an angle of 90 degrees from the pin. But the use of a valve of this design is impracticable, and lap is added to the valve. The adding of lap necessitates the eccentric centers of the Stephenson gear being set at some other angle from the pin than 90 degrees. The angle between 90 degrees and the point it is set is termed the *lap angle.* If the valve is given lead the eccentric center is set at a still greater angle from 90 degrees than the lap angle, and the angle between this point and the lap angle point is termed the *lead angle.* The total angle between 90 degrees from the pin and the point at which the center of the eccentric is set is termed the *angular advance.* With the Walschaerts and Baker gears the same effect is obtained by the combination lever's connection to the cross-head and the motion derived from it.

Cut-off.—Cut-off means the cutting off of live steam before the piston has completed its stroke, thereby utilizing the expansive force of the steam.

Compression.—Compression means shutting off the exhaust steam before the piston has completed its stroke. This remaining steam is compressed by the advancing piston and its pressure increased, forming a cushion that assists in stopping the reciprocating parts. The point of compression is where the exhaust edge of the valve completely closes the steam port, shutting off the exhaust steam.

Distribution of Steam.—The behavior of steam in a cylinder from the instant it is admitted to move the piston until it leaves the cylinder at exhaust, comprising its pressure throughout the stroke of the piston and the rate at which pressure change takes place. The points in steam distribution are *Admission, Cut-off, Expansion, Release* or *Exhaust,* and *Compression.*

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Release or Exhaust.—Release or exhaust means the release of the steam from the cylinder. This point is reached when the inside or exhaust edge of the valve opens the steam port and permits the steam to escape. It is at this point the engine exhausts or puffs. Pre-release is the release or exhaust of steam before the piston reaches the end of its stroke.

Expansion.—Expansion means the expanding of the steam contained in the cylinder at the time of cut-off to the time of release. The space the valve travels during expansion equals the outside and inside lap of the valve. Expansion explained more fully in Steam, Part IV.

Inside Clearance.—Inside clearance, sometimes called inside lead or exhaust lead, is not a portion of the valve, but is the space between the inside edges of the exhaust cavity of the valve and the bridges when the valve stands central upon its seat.

Lap.—Lap is a portion of a valve. Outside lap, frequently called steam lap, is that portion of a valve that overlaps the steam ports, when the valve stands central upon its seat.

Inside lap, sometimes called exhaust lap, is that portion of a slide valve that overlaps the two bridges of the valve seat when it stands central upon its seat.

Lead.—Lead is the width of opening of the steam port to admit steam to the cylinder when the piston is at the end or beginning of its stroke. Shown in Figs. 44 and 45.

NOTE.—Ordinarily lead remains constant with Walschaerts and Baker valve gears at all points of cut-off, while with Stephenson gear the lead varies, increasing as the link is hooked up from full gear.

Pre-admission.—Pre-admission, owing to lead of the valve, is the admission of steam to the cylinder before the piston has completed its stroke. Pre-admission is not necessarily proportional, as between the several types of valve gears having the same lead opening—*i.e.*, pre-admission with a certain type of gear, valve having a given lead, may take place earlier than in another type having the same lead, owing to the latter gear giving a much faster motion to the valve at or about the time the piston completes its stroke.

Travel.—Travel of the valve is the linear distance through which it travels. Over travel is the distance the steam edge of the valve travels after the steam port is wide open.

TYPES OF VALVE GEARS.

There are several types of valve gear used, but *Stephenson, Walschaerts* and *Baker* gears are the types in general use. Valve gear applied between a locomotive's frames is known as *inside gear;* applied outside of the driving wheels as *outside gear.*

All the previously mentioned gears can be applied either inside or

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outside, but it is customary to apply the Stephenson inside and both Walschaerts and Baker outside.

The Stephenson was practically the only valve gear applied to American locomotives until quite recently, but it is now being rapidly supplanted by outside gears, which are easy of access for inspection and lubrication.

The absence of valve gear between the frames permits of stronger bracing of the frames laterally, and owing to the necessity for heavy frames and their proper bracing there is hardly room enough between the frames of large locomotives for the Stephenson gear, having large eccentrics that occupy considerable space. Most of the connections of outside gears are made with pins and bushings, especially designed to resist wear, giving them the advantage of permanence of adjustment over a gear having large eccentrics, and usually they transmit motion to the valve in nearly straight lines, thus avoiding the springing and yielding of rocker arms, rocker shafts and transmission bars, which cannot be avoided on heavy locomotives using Stephenson gear.

The link of the Stephenson gear is given its motion from two eccentrics, one of which actuates the main valve so the engine will move forward, and the other so the engine will run in the opposite direction. The link of the Walschaerts gear and the gear connecting rod of the Baker gear receive their motion from a single eccentric in the form of a crank attached to the main pin, and this motion, supplemented by motion from the cross-head through the combination lever's connection, actuates the main valve.

With the Stephenson valve gear the lead varies as the position of the reverse lever is changed, increasing as it is moved from either full gear point toward mid-gear; while with Walschaerts and Baker gears the lead is constant or permanent and does not vary as the position of the reverse lever is changed, except on some very recently built locomotives having Walschaerts gear, which is so designed that the lead increases as the reverse lever is hooked up from full forward gear.

THE WALSCHAERTS GEAR.

The Walschaerts gear is of the radial type, and it employs a link which is trunnioned at its middle point. The link is rocked by means of an eccentric rod, whose motion is usually derived from a return crank, secured to the main crank pin. But as the Walschaerts valve gear, like many other devices, is merely a development, it would be best to start with the simplest form of valve gear and progress through the various stages of development.

Fig. 46 represents the simplest form of valve gear, viz., a single eccentric of the return crank form, actuating by means of an eccentric rod directly connected to the valve stem, a plain D-slide valve having

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neither lap nor lead. Assuming that the engine is to run forward, with main pin on back center, as shown, the eccentric crank pin must be on top quarter, 90 degrees ahead of the pin, and so the valve will be in a central position on its seat with all ports closed. If steam were admitted to a single engine with this kind of valve, crank pin as shown in figure, the engine could not start itself, but with another similar engine connected to the wheel on other end of axle, with crank pins at right angles to each other, as is usual on locomotives, the valve of opposite engine would be in position to admit steam behind its piston and start the wheels turning to the right. The eccentric crank of the engine shown in figure would then move the valve forward, uncovering the back steam port, admit steam behind the piston, and the engine would run forward. An engine with this kind of valve and valve gear could run in one direction only. If, with a single engine as shown in figure, it were desired to move the engine backward, and the wheel were moved to the left by some outside means,

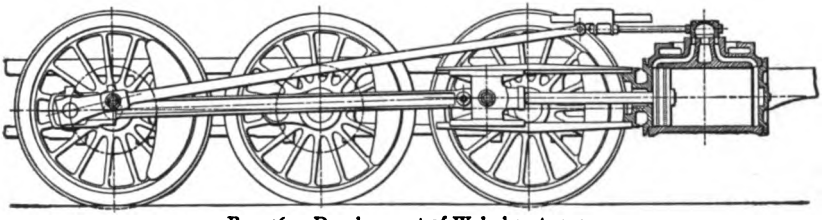

FIG. 46.—Development of Walschaerts gear.

with eccentric in position shown, the valve would move to the left and admit steam ahead of the piston, forcing the crank pin back again to its position on the back center. In order to make this engine run backward, the eccentric would have to be changed to a position opposite to that which it occupies, or to the lower quarter; and as the wheel turns to the left or backward the eccentric would be one-quarter of a revolution ahead of the main pin, moving the valve forward, and admit steam behind the piston as is necessary. It may be noted from the foregoing that with a valve gear and valve of this kind the eccentric must be set one-quarter turn or 90 degrees ahead of the main pin, considered from the point of direction of motion, no matter which direction the engine is to move.

The next stage in the development of this simple form of valve gear is to introduce some means by which it can be reversed. This might be accomplished by introducing a beam between the eccentric and the valve stem, pivoted at its center so that one end will move with and in the same direction as the eccentric and the other end in exactly the opposite direction.

Such construction is shown in Fig. 47. With valve stem at lower

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end of link and main pin on upper quarter, as shown in diagram "A," the eccentric will have moved the valve to its extreme forward position, opening the back port for the admission of steam behind the piston, and the engine will run forward. And, with the main pin and eccentric crank pin in the same position, if the valve stem were connected to the upper end of the link, as shown in diagram "B," the valve would be at a position to the extreme left, opening the front port and admit steam ahead of the piston. With a flexible valve stem, or radius rod, connected to a block that slides in a curved slot in the beam, or link, as shown, it is evident the engine can be reversed.

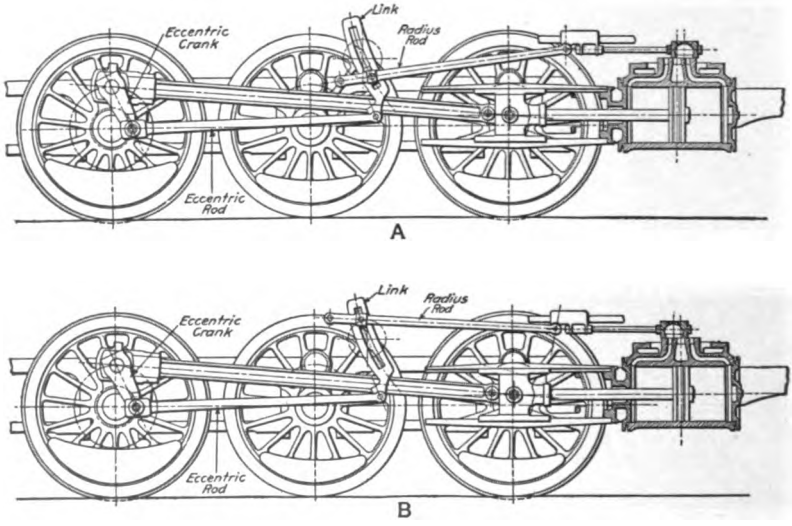

FIG. 47.—Development of Walschaerts gear.

An engine with a valve having neither lap nor lead would be an inefficient machine; for, as the valve would not close the port cutting off the admission of steam until in its central position on its seat; and, as with the eccentric one-quarter turn ahead of the main pin, it would not be in this position until the main pin is on its center, no matter what the travel of the valve, steam will be admitted to the cylinders throughout the full stroke of the piston, and the engine will use as much steam moving a light as a heavy load. In order to govern the period for the admission of steam—*i.e.*, give a variable cut-off, the valve must be redesigned and given lap, so that it will close the steam port before it reaches its central position. And, further, in order to secure the benefits of pre-admission of steam, the valve must be given lead.

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If lap and lead be given the plain valve under consideration, the valve gear must be so changed that the valve will be advanced from its central position a distance equal to the amount of lap plus the lead. This advancement could be obtained by moving the eccentric crank center more than one-quarter revolution ahead of the main pin, as shown in "A," Fig. 48, which shows the same valve gear as Fig. 47, excepting that the valve has been given lap and lead, and the eccentric center advanced. If, then, the link block is at the bottom of the link this advance has moved the valve forward a distance equal to the lap plus the lead, the back port will be opened for the admitting of steam and the engine will run forward. But if the link block is moved

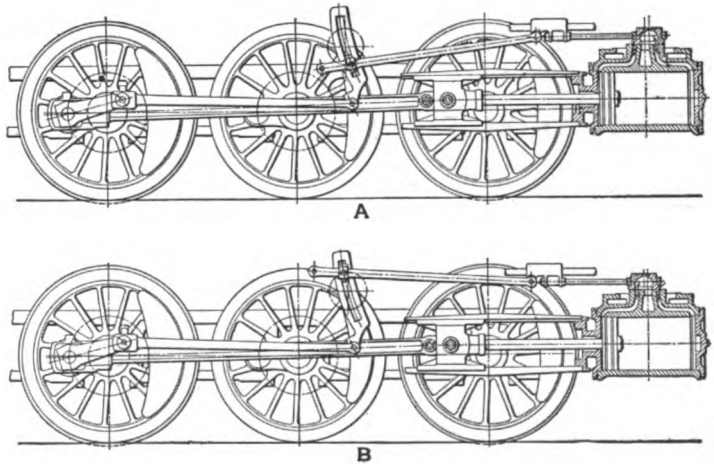

FIG. 48.—Development of Walschaerts gear.

to the upper end of the link, as shown in "B," Fig. 31, the advance given the eccentric has the opposite effect, the front port will be opened and it becomes impossible to reverse the engine. Therefore, with a reversible engine having but one eccentric, some means other than that of advancing or receding the eccentric's position relative to the main pin must be employed if the valve have lap and lead.

In the Walschaerts gear the motion required to displace the valve by an amount equal to the lap and lead is a combined motion derived from the eccentric crank and suitable connections with the cross-head.

The next step in the development of the Walschaerts valve gear is the introduction of the lap and and lead lever or combination lever. If the link block were standing at the center of the link, as shown in position "A," Fig. 49, there would be no movement of the radius rod, as the link swings back and forth owing to the action of the eccentric crank, because the center of the link block coincides with the center

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of the link support. Then if the radius rod were connected with the combination lever at the point " R," the upper end of lever connected to the valve stem cross-head at " V," the lower end to the cross-head arm by means of a short link, as shown, as the cross-head moves back and forth, point " R " being fixed, the point " V " will rotate about it and the valve will move back and forth. With main pin on forward center, as shown in position " A," the angle assumed by the combination lever has moved the valve back a sufficient distance to uncover the front port. With the main pin on the back center, as shown in position " B," the combination lever is inclined in the opposite direction, the valve has moved forward, and the back port is opened. This

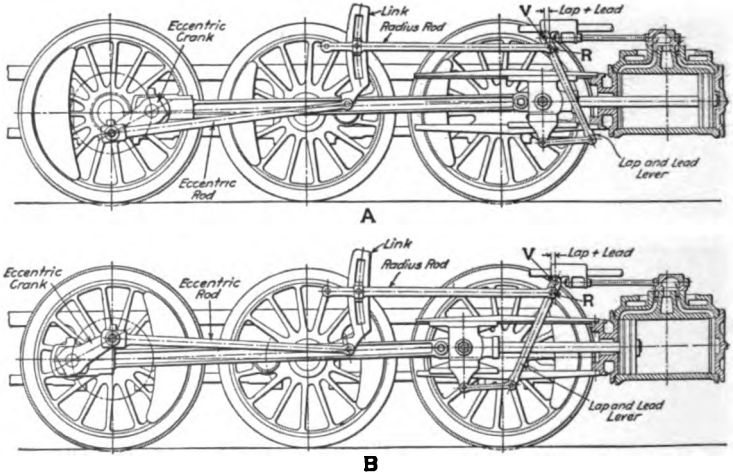

FIG. 49.—Development of Walschaerts gear.

is the way the lap of the valve is displaced and lead obtained with the Walschaerts valve gear. The combination lever is so proportioned that if the point of its connection to the radius rod be made a stationary fulcrum, and the cross-head moved a distance equal to the piston stroke, the valve will move a distance equal to twice the lap plus twice the lead. Therefore, when the piston is at the end of its stroke, the valve is displaced from its middle position a distance equal to the lap plus the lead. That this lead is permanent and does not vary as the reverse lever is hooked up, will be shown later on.

The position of the eccentric crank relative to the main pin depends on which end of the link is used for forward motion. If the bottom of the link is used for forward motion, inside admission, the eccentric crank is set one-quarter revolution behind the main pin when the engine is running forward, and one-quarter revolution ahead of it if

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the valves have outside admission. If the top of the link is used for forward motion, the eccentric crank is one-quarter revolution behind the main pin, outside admission, and one-quarter revolution ahead of it with inside admission. In all cases, if the valves have outside admission the radius rod is connected to the lap and lead lever below the valve stem, and above it, if they have inside admission.

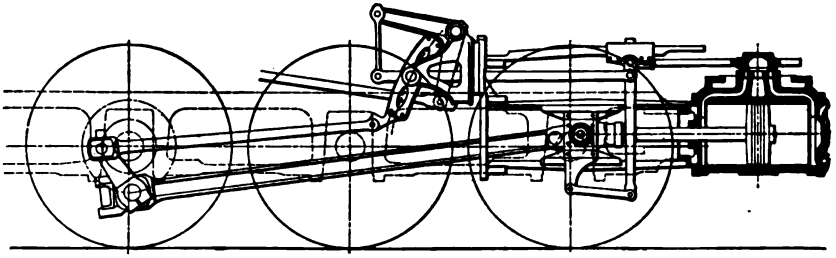

FIG. 50.—Development of Walschaerts gear completed.

As has already been shown, the valve receives its motion from two distinct sources: First, from the eccentric crank, which gives the long travel to the valve. Second, from the cross-head by means of the combination lever, which gives the effect produced by angular advance

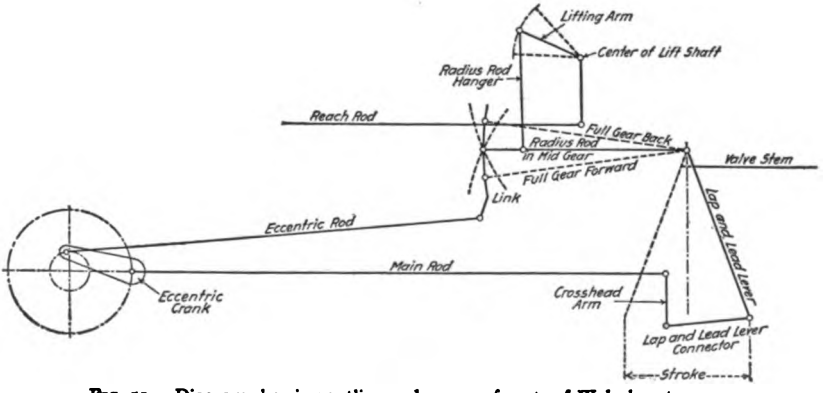

FIG. 51.—Diagram showing outline and names of parts of Walschaerts gear.

of the eccentrics in Stephenson gear, giving a short travel to the valve even if the eccentric rod were disconnected.

The simple form of direct valve gear shown in the first figure of this series has been developed to a gear that is reversible and has variable cut-off, and with the necessary reversing mechanism it becomes the complete Walschaerts valve gear, as shown in Fig. 50, which represents its application to a 2–8–0 type locomotive.

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Fig. 51 shows a general outline of the gear, arranged for outside admission valves, giving the names of the various parts as recommended by the American Railway Master Mechanics' Association.

THE BAKER GEAR.

The Baker gear is an outside gear with radial motion, though it has no link and sliding block. The valve movement in this type, as in the Walschaerts, is a combined motion derived from the eccentric crank and the cross-head.

The eccentric crank moves the radius bar, and the action this radius bar has on the valve is controlled by the reverse yoke. The

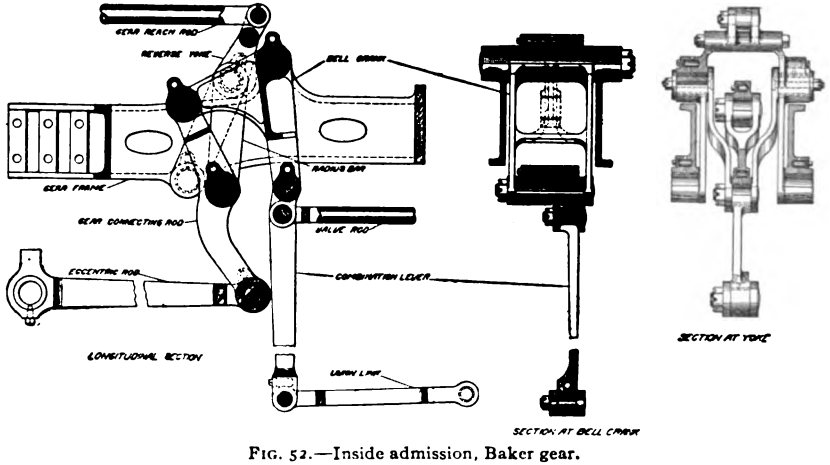

FIG. 52.—Inside admission, Baker gear.

radius bar and yoke take the place of the link and block of a link motion.

The cross-head moves the valve the amount of the lap and lead each way. This makes the lead constant and independent of the cut-off.

The eccentric crank always follows the main pin, being one-quarter revolution or 90 degrees from it, for either inside or outside admission valves. While lead with this gear is constant the pre-admission is variable; in full cut-off there being practically no pre-admission, and at 25 per cent. cut-off about ⅞ inch pre-admission.

Figs. 52 and 53 show the two arrangements of Baker gear: Fig. 52 the gear used with inside admission, and Fig. 53 the gear used with outside admission.

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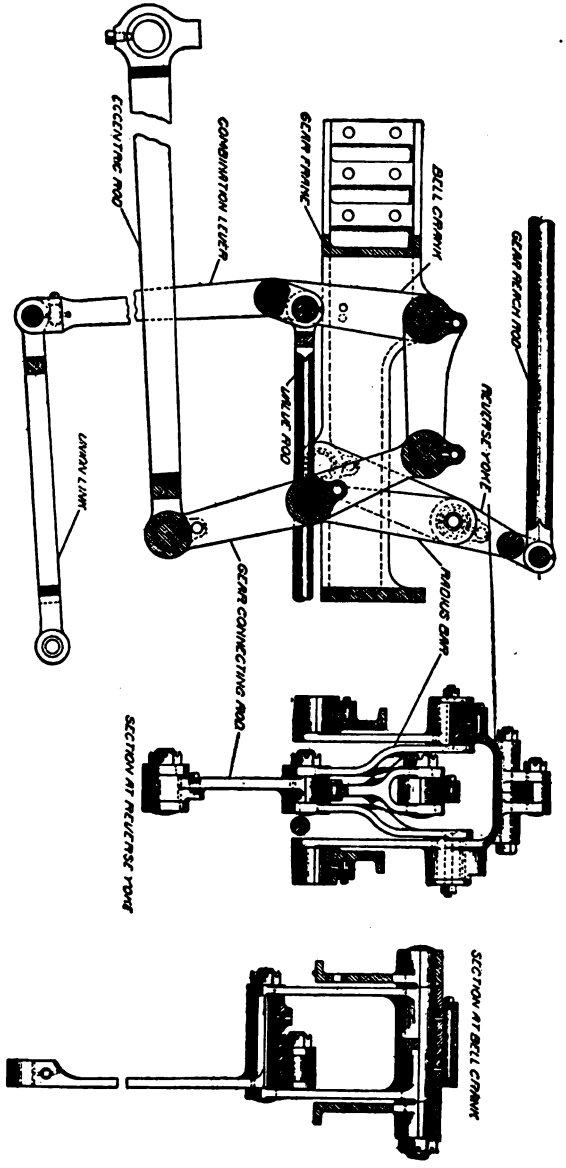

FIG. 53.—Outside admission, Baker gear.

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THE STEPHENSON GEAR.

The Stephenson gear as applied to locomotives has four eccentrics, two for each engine, *forward motion* and *backward motion*, keyed to an axle. Working on the eccentrics are straps that are attached to one end of the eccentric rods, while the link is connected to the other. In the slot of the link is the link block, a bearing for the rocker arm connection, which transmits the motion of the eccentrics to the valve by the transmission bar (if used), valve rod, and stem.

To reverse the direction of motion of a locomotive having Stephenson gear, the position of the link is changed, for one end of the link is connected to the forward motion eccentric and the other end to the back motion. The position of the link is controlled by the reverse lever. When it is in the forward end of the quadrant, the link block is opposite the end of the forward motion eccentric rod, and the engine is in *full gear forward;* when in the back end of quadrant the link block is opposite the end of the backward motion eccentric rod and

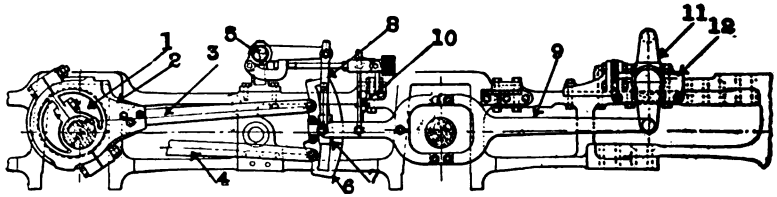

FIG. 54.—Stephenson gear.

1. Eccentric.
2. Eccentric strap.
3. Forward motion eccentric rod.
4. Back motion eccentric rod.
5. Lift shaft.
6. Link.
7. Link block.
8. Link hanger.
9. Transmission bar.
10. Transmission bar hanger.
11. Rocker arm.
12. Rocker box.

the engine is in *full gear backward*. When the reverse lever is in the center of the quadrant the link block will be in the center of the link slot mid-way between the end of the forward motion and backward motion eccentric rods, the engine is then said to be in *mid-gear*.

With outside admission, indirect motion, the forward motion eccentric follows the main crank pin, and backward motion eccentric moves ahead of the main pin when the engine is running forward; or, the eccentric controlling the valve follows main pin regardless of the direction of motion. While with inside admission, indirect motion, the forward motion eccentric moves ahead of the main crank pin, and backward motion follows it when the engine is running forward. With outside admission valves, locomotive starting from either center, the valve must move in the same direction the piston moves to properly admit steam to the cylinder.

Fig. 54 presents a view of the Stephenson gear as applied to a 4–4–2 type of locomotive, followed by a numbered list of parts.

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PART VIII

RUNNING AND FIRING

PREPARATION AND INSPECTION, TOOLS AND SUPPLIES, RUNNING, FIRING.

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PREPARATION AND INSPECTION.

LOCOMOTIVE terminals are the places where locomotives are sent to be inspected, fires cleaned, tenders replenished with coal and water, sand boxes refilled, and necessary minor repairs made, including periodical testing of stay bolts, renewal of those found defective, and washing out of boilers. A locomotive terminal is in charge of a foreman, to whom engineers and firemen report before going on duty. It includes engine house, adjacent engine storage tracks, inspection and fire-cleaning pits, ash, coal and sand handling and loading apparatus, and the works requisite for making running repairs to locomotives, preparatory to their being dispatched for service.

Engineers and firemen report for duty at the engine house, where their locomotive for the trip is assigned them, and they should observe whether any new special instructions have been posted on the bulletin board since their last trip, and if so, make sure they thoroughly understand them. Engineers should ask to see repair work reports of engineers who had the locomotives on previous trips. By this practice they can note whether or not the work has been done and will know just what parts to pay especial attention to, a matter of importance if journals or pins have been running hot.

When taking charge of a locomotive and preparing it for a trip the engineer should first observe that the water in the boiler is at a safe height, and assure himself that the firebox and tube heating surfaces have not been overheated and are in safe condition. He should then inspect the locomotive and equipment, assure himself that the locomotive and its appurtenances, such as injectors, air pumps and air brakes, lubricators, and steam heat apparatus, are in proper order; that a full equipment of tools, train signals ready for immediate use, water, coal, and oil are at hand. At the end of the day's run or trip the inspection should be repeated and all defects or disorders reported as prescribed by the railroad company's rules.

The engineer should try the gauge cocks, see that all are in good working order; examine the glass water gauge, blow it out and compare its water indication with that shown by the gauge cocks. Gauge cocks should be used frequently not only to compare the height of water indicated by the glass water gauge but also to keep them in good order. Leaks about glass water gauges are liable to make them indicate more water than is in the boiler.

NOTE.—The proper method of blowing out the glass water gauge is as follows: Shut top valve, open drain valve, leaving bottom valve wide open, allow steam and water to blow out of drain pipe until it is clear of mud, then shut the bottom valve and open the top wide, allowing steam to blow out until water and steam from the drain pipe is clear.

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When preparing a locomotive it is good practice, particularly if it has been standing for some time during cold weather, to open the cylinder cocks, establish a circulation of steam by slightly opening the throttle, and slowly, uniformly heat the steam passages, steam chests and cylinder walls. These parts are cast iron and their sudden, uneven heating causes unequal expansion to take place, which may result in their eventually cracking.

Firemen also should observe that the water in the boiler is at a safe height, and that heating surfaces have not been overheated and are in a safe condition. They should assist engineers in inspecting equipment and supplies, prepare fires, fill lubricators, draw requisite supplies, including oil and waste from the store house, fill, clean, trim and light lamps and train signals, and fill the tank with water.

A thorough inspection of a locomotive would embrace parts and features connected with them as follows:

Inspect crown sheet, inside firebox sheets, crown bolts and stay bolts for leaks, observing whether there are any indications of heating surfaces having been overheated owing to low water; and tubes to ascertain if leaking or clogged.

Note that gauge cocks are fitted with sounding pipes of proper length and the drip pan and pipe are in good order.

Note that the safety valves lift at the prescribed working steam pressure by comparing their point of lifting with the pressure indication of the steam gauge and that shown on the badge plate.

Note the main reservoir, brake pipe and brake cylinder air gauges and see that they indicate pressures required.

Try both injectors and note that they raise water promptly and properly deliver it to the boiler.

Open surface cock to insure its working properly and observe that the connections are unobstructed by scale or other foreign matter.

When a locomotive is delivered at an engine terminal after a day's run or trip and it is known to be due for boiler washing or boiler work that requires blowing off the water or steam pressure, it should be noted whether throttle stem or any of the valves or steam connections about the boiler need repacking.

Inspect hand railings and headlights to see that they are in good order and properly secured.

Inspect grab irons, foot-boards, running boards, steps and safety appliances to see that they are in good order.

Inspect coupler and pilot to see that they are properly secured and of proper height.

Inspect sand pipes and sanding apparatus to see that sand will run properly both sides, and note that pipes deliver sand on top of rail.

Inspect engine truck wheels and driving wheels for loose wheel fit on axles, loose pins in driving wheels, collar bolts and nuts, periphery of all wheels for sharp or thin flanges.

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Inspect engine frames for cracks and for disorders, as loose bolts at cylinder saddle and tail piece connections, and working loose at splices. Loosely fitting parts, as loose tires on driving wheels, loose wheels on axles, loose frame splices and braces, and loose rocker boxes on frames, will be shown by oil, moisture, and iron rust oozing at defective places.

Inspect firebox expansion pads and braces to see that the bolts are tight and properly fitted and note that excessive lost motion has not developed between firebox expansion braces and shoes.

Inspect main rods and side rods: Main rods, for loose or defective keys and set screws in both front and back ends; side rods, for loose crank pin bushings and loose knuckle joint pins; and both main and side rods for loose or missing oil cup lids, grease cup lids or plungers.

Inspect cross-heads and guides for loose cross-head wrist pin and piston rod working loose in its fit, and for loose guide bar nuts and bolts.

Inspect cylinders, cylinder saddles, and guide yoke for indications of working loose on frame, and cracks about cylinders, saddles and outside steam pipe joints, if locomotive is so fitted, that allow leakage of steam.

Inspect all bolts that are fitted with taper pins and split or cotter keys used as safety keys in connection with either washer or castellated nuts, noting that they are in place and in good condition.

Inspect frame pedestals and driving boxes for loose pedestal braces and wedge bolts, broken driving box shoes, loose driving box oil cellars and cellar bolts.

Inspect valve gear: Inside gear, for eccentrics loose on axle, loose bolts in eccentric straps and rods, loose link block bolts, rocker boxes working loose on frame, loose or defective bolts in link hangers and transmission bars and hangers, missing or defective safety pins. Outside gear, for loose nuts, bolts and missing or defective pins in eccentric rods, links, link blocks, radius rods, and combination lever. Both gears, for loose bolts in reach rod, lift-shaft and lift-shaft hangers, and lift-shaft bearings working loose on frames.

Inspect driving and engine truck springs, spring saddles, and equalizing rigging, for broken spring leaves, cracked or broken spring hangers, defective hanger bolts and irregular position of equalizers.

Inspect tail rails or rear ends of frames, for working loose.

Inspect draft apparatus between engine and tender, which include draft bar, safety bars or chains, chafing block, buffer, etc.

Inspect smoke box for cracks, loose fitting door, hand hole side caps and hopper slide.

Inspect feed pipes to injectors, feed hoses, air brake and steam heat hoses or connections, between engine and tender, for leaks, defective hoses, and defective joints and couplings.

Inspect ash pan for cracks or holes that would allow fire to be dropped, defective or improperly secured operating mechanism of ash pan doors or slide.

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Inspect grates for broken or displaced grate bars, broken or disconnected shaking grate rigging and improperly secured drop grate levers.

Inspect whistle and bell ropes, noting that they are properly applied and in good condition.

Inspect all boiler wash-out or hand hole caps for improper application and leakage.

Inspect all communicating pipes on front of engine and rear of tender for defective couplers and gaskets, noting that couplers are in proper position for coupling, and that there is circulation of steam in steam heat pipes so that freezing will be prevented.

Inspect superheater damper operating device, noting that counter weight is down when the throttle is shut off and that it rises when the throttle is opened and steam admitted to the cylinders.

TOOLS AND SUPPLIES.

Engineers should inspect the entire equipment of tools and supplies on their locomotive previous to departing from a terminal, and if

Kind	Service		
	Passenger	Freight	Shifting
Brooms	1	1	1
Blocks, Crosshead	2	2	..
Bucket	1	1	1
Cans, Oil and Grease (Combined)	1	1	1
Cans, Valve Oil	1	1	1
Cans, Hand oiler	2	1	1
Chisel	1	1	1
Chisel Bar	1	1	..
Clamps, Valve Stem	1	1	..
Compound Bucket	1	1	..
Carbon Bar [1]	1	1	1
Hammer	1	1	1
Hooks, Fire	1	1	1
Hooks, Packing	1	1	1
Irons, Sponging	1	1	1
Pick, Coal	1	1	1
Pokers	1	1	1
Push Poles	..	..	1
Pinch Bar	1	1	..
Rope, Tank	..	..	1
Scraper	1	1	1
Shovels	2	2	1
Shaking Grate Lever	1	1	1
Wrench, Air pump Spanner	1	1	1
Wrench, Alligator No. 3	1	1	1
Wrench, Alligator No. 4	1	1	..
Wrench, Grease Cup	1	1	1
Wrench, Monkey (2 sizes)	2	2	2

[1] Oil burners only.

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any of such equipment is missing or found defective they should arrange for replacement.

When locomotives arrive at engine terminals, engineers and firemen should place tools and supplies in places provided for them on locomotives and tenders, lock the tool boxes and closets and deliver the keys at the proper place. Some railroads require engineers to report the condition of tools and supplies at the end of trip.

On page 168 is a list of tools that includes practically all comprised in a locomotive tool complement for most railroads.

In addition to the list of tools locomotive equipments usually contain the following furnishings:

Kind	Service		
	Passenger	Freight	Shifting
Arm Rests	2	2	2
Back Curtains	1	1	1
Bell Rope	2	2	2
Books for Fuel	1	1	1
Boards, Coal (Set)	1	1	1
Bucket, Tank	1	1	1
Boxes, Tin	2	2	2
Boxes, First Aid	1	1	1
Cooler, Water	1	1	1
Cup, Drinking	1	1	1
Crank Pin Blocks	2	2	..
Emergency Knuckle	1	1	..
Engine Cab Sand Funnel[1]	1	1	1
Box for Sanding Tubes	1	1	1
Flags, Green	4	4	4
Flags, Red	1	1	1
Flags, White	2	2	2
Flag Holders	2	2	2
Fusees (Set)	1	1	1
Hose, Sprinkler	1	1	1
Hose, Extra, Air Brake	1	1	..
Hose, Extra, Signal	1	..	..
Hose, Extra, Steam Heat	1	..	..
Lamps, Classification	2	2	2
Lamps, Markers	2	2	2
Lamps, Hand, Red	1	1	1
Lamps, Hand, White	1	1	1
Lamp, Steam Gauge	1	1	1
Lamp, Water Gauge	1	1	1
Locks (Set)	1	1	1
Side Curtains	2	2	2
Torpedoes (Set)	1	1	1
Torches	2	2	1
Tank Air Gauge[1]	1	1	1

[1] Oil burners only.

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RUNNING.

After signal to start is given by the person in authority, the bell should be sounded before starting. When starting a train the brake valves should be in the proper position, reverse lever in full forward notch, throttle opened carefully, and start slowly, preventing damage to draw bars and draft rigging. Where two or more locomotives are attached to a train the leading locomotive should, when starting the train, start first, taking up the slack of the train before steam is admitted to the other locomotive or locomotives. This minimizes the danger of damage to car couplings and draft gear, and when making a stop, steam should be shut off on the leading locomotive last in order to avoid the shock incident to the following locomotive or locomotives suddenly bumping together the slack between couplings.

If sand is necessary it should be used in small quantities and it should be known it runs on both rails, for if it runs on but one rail there is a possibility of twisting an axle, breaking a crank pin, or pulling it out of a wheel center, or stripping the rods off. If the engine slips sand should not be dropped until after the throttle valve is shut off, or, in other words, a slipping engine should not be "caught" on sand, as the same damage is liable to result as when sand runs on but one rail.

As the speed of a locomotive increases the reverse lever can be hooked toward the center of the quadrant, which makes point of cut-off earlier in stroke, and throttle opened wider until speed has been attained.

Point of *cut-off* affects *coal consumption* and efficiency of a locomotive to a greater extent than any other feature of its operation, and theory teaches that steam should be admitted to the cylinders at full boiler pressure, and that the point of cut-off should be as early in the stroke as will enable the locomotive to perform required service; but in practice this proposition is subject to considerable modification, and unless the locomotive be equipped with a superheater, point of cut-off should not take place earlier than 25 per cent. of stroke. For cylinder condensation becomes so great when expansion is carried to the limit permissible with ordinary locomotive valve gears that the loss from condensation becomes greater than the gain from expansion. Reliable tests have demonstrated that coal economy will be effected (superheater locomotives excepted) and smoother working machine conditions will be obtained by working the locomotive (except when starting) with fully opened throttle when point of cut-off is at one-quarter stroke or later; and if full throttle, cut-off at one-quarter, gives more power or greater speed than required, the cut-off should not be changed but the throttle partially closed.

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The great extent of cylinder condensation at early cut-off becomes apparent from an inspection of the following table, which shows the amount of steam condensed the stroke at various points of cut-off:

Condensation = 35	per cent.	at	20.5	per cent.	cut-off.
Condensation = 25	per cent.	at	25	per cent.	cut-off.
Condensation = 20.5	per cent.	at	30	per cent.	cut-off.
Condensation = 16.5	per cent.	at	35	per cent.	cut-off.
Condensation = 16	per cent.	at	40	per cent.	cut-off.
Condensation = 14	per cent.	at	50	per cent.	cut-off.
Condensation = 13	per cent.	at	60	per cent.	cut-off.
Condensation = 12	per cent.	at	70	per cent.	cut-off.

With large, wide firebox types of locomotives it is practicable to permit the reverse lever to remain low in the quadrant for some time without pulling the fire or losing steam pressure, and it would seem good judgment on the part of engineers to take advantage of this when starting from stations in order to more quickly accelerate.

When making station stops with heavy trains it is good practice to reverse the engine as soon as the train stops, and, if necessary, open the throttle slightly for the purpose of getting the slack between the engine and the train, though care should be taken not to move the train.

Feeding Boilers.—The regulating of feed water has a greater effect on efficient performance of locomotives than any other feature connected with their operation, not even excepting their firing; for the manner in which water is fed to the boiler directly affects steam pressure and fuel consumption, and has a marked secondary effect on boiler repairs, tube leakage, and the effectiveness of valve and cylinder lubrication.

In a boiler under steam the water is constantly in motion, owing to the physical effect that heat has on its particles, and this motion is termed *circulation*, as there is a tendency for the water to flow in currents. Circulation tends downward at the comparatively cool parts of the boiler, upward at the hot parts or close to the heating surfaces, being strongest about the firebox, and it is impelled somewhat by the steam arising from the hot sheets. The intensity of water currents in a locomotive boiler is proportional to the quantity of heat generated in the firebox, circulating quite swiftly when the boiler is generating steam at its maximum capacity, and ceasing almost entirely when the locomotive is at rest with banked fire.

Circulation is a natural process, and takes place in a boiler under all conditions when heat is applied to the heating surfaces, yet its progress can be promoted by a well-designed boiler and the practice of proper methods of feeding with water and firing. Circulation is

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beneficial in several ways: It tends to maintain equal temperature throughout the boiler, adds to the water's ability to absorb heat, decreases the liability to waste heat owing to priming, and has a scouring action that tends to prevent scale formation on the heating surfaces.

The importance of maintaining equal temperature, or of uniform variation of temperature, throughout a locomotive boiler cannot be overestimated; for temperature effects are the principal causes of a boiler's deterioration. Sudden or local expansion and contraction of boiler sheets, owing to varying temperature of surrounding water or violent changes in firebox temperature, are the most destructive features and the cause of most boiler disorders, including that most annoying of them all, tube leakage.

The beneficial effects of equality and uniformity of temperature become more clear when it is learned that the top rows of tubes in a firebox give practically no trouble from tube leakage as compared with the bottom rows, and yet the top rows are subjected to a somewhat higher temperature. But the water surrounding top rows of tubes usually remains at a more nearly constant temperature than that surrounding the bottom rows; for the comparatively cold entering feed water goes to the bottom of the boiler, and, unless thorough circulation is in progress, local variations of temperature ensue, consequent unequal contracting and expanding of tubes take place, the tubes are loosened in the tube sheets, usually the bottom rows, as here is where the greatest temperature variations occur, and leakage results.

Of course, it is impracticable to maintain equal temperature throughout a locomotive boiler under all conditions of service, but by the exercise of good judgment and skilful practice on the part of engineers and firemen in the feeding of water to boilers and the firing, variations of temperature can be made fairly uniform, and very little damage will be done tube joints when they are subjected to equal variations of temperature; that is, tube ends fitted in a tube sheet can be heated and cooled a great many times, though not become loosened, if all connected parts are heated and cooled uniformly.

Circulation is most active when a locomotive is at work with a thoroughly burning fire, and this is the proper time to feed the boiler with water in order to obtain desired equality of temperature. If necessary to feed the boiler when running with steam shut off or while the locomotive is standing the blower should be applied so as to maintain high temperature about the heating surfaces and keep up circulation. The steam pressure should be kept as near constant as practicable, for in a theoretical sense steam and water in contact in a boiler are of equal temperature, which varies according to pressure, though this is true only when the water is in active circulation. And so to sum the matter up, the steam pressure should be kept constant,

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or sudden variations prevented, from the time the locomotive is prepared to go out until delivered at the ash pit after the day's run or trip, and the fire should be actively burning and hot when water is being fed to the boiler.

When starting, the water in the boiler should be at such a height that the locomotive can be started without priming, but should be sufficient to run a considerable distance so the fireman can build up and get the fire in proper order. Water should not be fed to the boiler of locomotives at rest up to the time throttle is about to be opened, as the cool water introduced during the time throttle was closed causes a lowering of temperature of water in the boiler, a corresponding decrease in steam pressure, necessitating heavy firing and consequent waste of coal in order to regain lost steam pressure.

Water in the boiler should be carried low enough to insure dry steam, being careful, however, that when near the top of ascending grades and about to pitch over to descending grades there is sufficient to keep the heating surfaces covered. The least amount that may be carried in a boiler at any time must be sufficient to cover all the heating surfaces, while the greatest amount that may be carried should not cause the boiler to prime.

On through trains or those running considerable distances between stops, the water should be fed at a rate corresponding to that at which it is passing from the boiler, and the water level should be kept at constant height in the boiler; while on local or trains making frequent stops a little water may be lost between stops, which can be regained while drifting into or standing during the stops.

When running, the height of water in the boiler should be judged by frequent testing of the gauge cocks, using the glass water gauge as an auxiliary only. On locomotives with large boilers and great steam generating capacity, when the throttle is open the glass water gauge usually indicates from two to three inches more water than when the throttle is shut off.

As lubricants can be washed from valve seat surfaces and cylinder walls by water, it is important that water be maintained at such a height in the boiler that it will not be carried to the cylinders with steam.

Priming or foaming of water in a locomotive boiler will be indicated by the appearance of white steam at the stack and cylinder cocks, and is usually accompanied by a peculiar muffled sound of the exhaust, which can be observed best when the fire door is open. The water will also rise in the glass water gauge and it will not indicate correctly the quantity of water in the boiler. When there are indications of priming or foaming, or that water is working into the cylinders, the cylinder cocks should be opened at once, otherwise the cylinder heads or pistons may be broken. The throttle valve should be either partly

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or entirely closed. When this is done the foaming will usually cease, and so the actual height of water may be determined.

The causes of foaming are impure water or grease, animal oil or soap getting into the boiler. As impurities, grease, etc., float on the surface of the water, one of the best methods of affording relief, if the boiler foams, is the use of the surface cock. When using the surface cock for blowing off impurities, it is necessary to blow the water level down until its surface is even with the opening of the surface cock or the impurities on the surface will not be blown out.

Running and Firing Superheater Locomotives.—The mode of operating locomotives equipped with superheaters is practically the same as that of locomotives using saturated steam, though in order to obtain efficient performance from superheating apparatus there are a few details involved that must be given attention. The following notes refer to their operation by engineers and firemen, and while most of them are applicable to all types of superheaters, there are a few applicable to individual types only.

All Types.—When starting the reverse lever should be put in full gear to insure oil distribution the full length of the valve bushing. Cylinder cocks should be kept open when starting until dry steam appears.

When using steam, working conditions permitting, keep the superheater full of steam by opening the throttle fully, and as far as practicable regulate the locomotive's power and speed by the use of the reverse lever.

On account of the large diameter of cylinders generally used in superheater engines the throttle must be opened slowly and special care taken to prevent slipping of drivers.

Generally, superheater locomotives should be operated with short cut-off and, when working conditions permit, full throttle; though it is practicable to operate at a relatively longer cut-off than usual on saturated steam locomotives without lowering the efficiency.

The water level in the boiler should not be allowed to get so high that there might be danger of water being carried over into the superheater and cylinders, as this defeats not only the object for which the superheater was designed but the lubricant may also be washed from the valve chamber and cylinder walls. Moreover, any water carried into the superheater will be converted into steam in the superheater, generating pressure that may continue to pass to the cylinders even after the throttle valve has been closed. As the superheater tubes have considerable volumetric space, and as water may inadvertently be carried into the superheater, superheater locomotives should never be moved without required air pressure and brakes in operative condition, for steam may continue to flow to the cylinders for some little time after the throttle is closed.

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When handling the locomotives about the engine house, yards, etc., before the cylinders are warmed, the cylinder cocks should be kept open until dry steam appears.

The feeding of valve and cylinder lubricant should be continual while the locomotive is in service. Superheated steam is dry, and there being no water in the steam to act as a lubricant on the valve chamber and cylinder walls, more generous lubrication must be provided than on saturated steam locomotives. Ordinarily the valves should receive 8 to 15 drops of valve lubricant per minute, and, when oil pipes direct to cylinders are provided, which is usual on superheater locomotives, the cylinders should receive half that number. Lubricators should be started to feed at least 15 minutes before starting the locomotive, to insure thorough lubrication before starting.

Where a drifting throttle or an attachment for admitting steam to the cylinders when the throttle is shut is not used, it is advisable, in order to avoid the suction of hot gases from the smoke box into the steam chest and cylinders, to keep the throttle slightly open when drifting or making stops, as by passing a very slight amount of steam through the cylinders, the smoke box gases cannot be drawn into the exhaust column. The throttle should be completely closed just before coming to a full stop.

The firing should be light and regular to produce as high flame temperature and as perfect combustion as possible in the firebox, for a smoky fire has a low flame temperature, and reduces the degree of superheat. In connection with this latter feature it should be borne in mind that the pressure indications of the steam gauge supply no information as to the steam's temperature above the saturation point; that under certain conditions the locomotive might be operating with the maximum allowed steam pressure and yet the steam not be superheated, in which event the efficiency will not be any greater than if saturated steam were used. Under these circumstances, something more than observing the steam gauge is required in order to get high efficiency from superheaters, and at present there is a growing sentiment that the future superheater locomotive will have an apparatus located in the cab that will indicate the temperature of the steam passing to the valve chambers.

Leaks in the front end of superheater units, flues stopped up and derangement of draft appliances not only affect the steaming of the locomotive, but reduce the degree of superheat and should be reported and corrected at once. Blows in cylinder and valve packing should be reported and receive proper attention, as they will cause scoring, due to removal of oil from wearing surfaces.

Swabs should be applied and maintained in good condition on piston rods and valve stems. The same kind of oil should be used on swabs as is used for cylinder lubrication.

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Damper Types.—To prevent burning the superheater tubes when there is no steam passing through them, the front end of the large flues discharge into a chamber that is separated from the rest of the smoke box by a partition and an automatically operated damper. This damper is held open by the pressure of steam from the steam chest acting on a piston in the cylinder that operates the damper, permitting the hot gases to flow through the superheater flues. It is closed by a weight or a spring, as soon as the steam is out of the steam chest, and stops the flow of hot gases through the large flues.

The engineer should know that the superheater damper is open while using steam and closed when the steam is shut off. If the locomotive does not steam freely it should be ascertained that the superheater damper is open.

The superheater damper should be closed when the blower is used in the process of firing up.

Running Baldwin Balanced Compound Locomotives.—To start the locomotive with a train, place the reverse in full gear, forward or back, depending on direction of motion, move cylinder cock lever forward, open the starting valve which allows high pressure steam to pass to the low pressure cylinders, then open the throttle to admit steam, and as soon as possible, when the cylinders are free of water and the train under good headway, close the cylinder cocks and the starting valve. After the starting valve is closed and as the speed of the train increases, the reverse lever should be hooked back a few notches at a time until the full power of the locomotive is developed. If, after moving the reverse lever to the last notch, which cuts off the steam at about half-stroke in the high pressure cylinder, it is found that the locomotive develops more power than required, partially close the throttle, reducing the flow of steam to the cylinders. On slightly descending grades the steam may be throttled very close, allowing just enough in the cylinders to keep the air valves closed. If the descent is such as to prevent the use of steam, close the throttle and move the reverse lever gradually to the forward notch and open the starting valve. This allows air to circulate through the starting valve from one side of the piston to the other, relieves the vacuum and prevents the oil from being blown out of the cylinder. On ascending grades with heavy loads, as the speed decreases, the reverse lever should be moved forward sufficiently to keep up the required speed. If, after the reverse lever is placed in the full forward notch, the speed still decreases and there is a probability of stalling, the starting valve may be used, admitting live steam to the low pressure cylinders. This should be done only in case of emergency and the valve closed as soon as the difficulty is overcome.

Economy in operation of compound locomotives depends greatly on greater range of expansion of steam in the cylinder, effecting a reduc-

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tion in cylinder condensation, and so it should be borne in mind that, to obtain highest efficiency with this class of locomotive, the reverse lever must be used to regulate the cut-off to suit load conditions.

American Locomotive Company's Articulated—Starting.—Always open the cylinder cocks in starting. Usually the American articulated compound locomotive will start the train when the throttle is opened in the ordinary way with the reverse lever in the position required for the weight of the train or ordinarily in the extreme notch. If the locomotive fails to start the train when operated in this way, change it into simple working by turning the handle of the emergency operating valve in the cab so that it points backward. This same course should be followed if the engine is about to stall on a heavy grade. If the speed is over three or four miles an hour, no increase in power will be obtained by changing the locomotive into simple working, for the reducing feature is so designed that no increase of power is obtained at greater speed, which is in order that the emergency feature will not be misused, with injurious effect on the machinery and the sacrifice of economy in fuel consumption.

There is no increased tendency for the locomotive to slip when working simple; and moreover, when it does slip, the slipping is automatically arrested after only a few inches of movement of the piston. If the locomotive starts to slip, it is advisable to use sand should the rail conditions be at all unfavorable.

The engineer can easily know whether the locomotive is working simple or compound either by the sound of the exhaust or by the position of the emergency operating valve in the cab. When working simple there are eight exhausts to each revolution of the wheels; and only four when working compound. In the former case the exhaust has more the sound of a continuous blow, the separate exhausts being less distinct. When working compound, the handle of the emergency operating valve, as stated, points *forward;* and *backward* when working simple.

It is very important for the engineer to remember that, the locomotive having been changed into simple by opening the emergency operating valve (N) Fig. 10, in the cab, it is necessary to close this valve (that is, turn it so that the handle points *forward*), in order to change the locomotive back to compound or normal working. With the emergency operating valve closed, the steam will be exhausted from the chamber (G) in front of the piston (8). The tension of the spring assisted by the steam pressure upon the inner end of the emergency exhaust valve (6) will then return that valve to its seat, thus preventing the exhaust steam from the high pressure cylinders escaping to the stack. A few exhausts from the high pressure cylinder will, then, soon raise the pressure in the chamber (F) and force the intercepting

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valve (2) and with it the reducing valve (1), to assume the compound position, as shown in position 3, Fig. 11.

If, upon starting the locomotive, it is desired to prevent the valves from changing automatically to the compound position, the emergency valve (6) may be opened in advance by opening the emergency operating valve (N), Fig. 10, turning the handle *backward*. This, as previously explained, will prevent the pressure in the chamber (F) from rising sufficiently to force the intercepting valve (2) open.

In changing from compound to simple when running, the sudden unbalancing of the intercepting valve (2) tends to close this valve rapidly, with the result that it would slam, were it not for the dash-pot previously mentioned which prevents this. The dash-pot piston (3) at the outer end of the intercepting valve stem works in the cylinder (H) formed in the outer end of the intercepting valve chamber head (4). When the intercepting valve is forced inward under full pressure, its too rapid motion is prevented by the slow escape of the air from under the piston (3) through the small port (J). This is practically the only function of the dash-pot. The port (K), extending through the center of the intercepting valve stem half way to the inner end, permits the escape of any steam that may leak past the small rings on the intercepting valve stem and reducing valve (1).

If the low pressure engine fails to start when the throttle is open, the trouble may lie in the reducing valve (1) having stuck in the closed position, due to the fact that it had not been properly lubricated or some foreign matter had worked into the bore of the valve. In such an event the admission ports (B), Fig. 11, would be closed and no steam could get to the low pressure cylinder.

Such difficulty can ordinarily be remedied by giving the reducing valve a little more feed of oil for a few minutes; or, if necessary, the cover of the dash-pot (H) may be removed and with a piece of bent ¼-inch wire the reducing valve (1) may be moved in and out a few times, after which it will probably clear itself when the throttle is open.

Drifting.—When drifting, the reverse lever should be placed at a point that will give cut-off at three-quarter stroke or later.

Care of Special Parts.—The oil cylinder of the power reversing gear should always be kept full of oil. The piston rod packing of the oil cylinder should be kept in good condition so as to prevent leakage.

If the reversing gear operates too rapidly it indicates that there is not sufficient oil in the oil cylinder and this should be refilled and the leakage stopped.

If the reversing gear is not adjusted properly so that the latch of the main reverse lever does not engage with the teeth of the quadrant, the trouble should be remedied as soon as possible. If not properly adjusted, the locking of the reverse gear will be put almost

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entirely on the latch of the auxiliary lever, which is not designed for such duty and would quickly wear.

The by-pass valves should be taken out and cleaned periodically to prevent them from being gummed and sticking. When the locomotive is first put into service, these valves should be closed quite frequently for a few times so as to keep them free from the core sand which is sure to work into them. Afterwards they will require only ordinary attention to work properly. When these valves are properly performing their functions the locomotive will drift freely. If they stick open it will cause a severe blow, while if stuck in the closed position it will cause a pounding in the low pressure engines.

The relief valves in the low pressure steam chests should be tested occasionally to see that they correctly set at 45 per cent. of the boiler pressure, as these valves relieve any excessive pressure in the steam chests.

Lubrication.—Give the intercepting valve a liberal feed of oil for a minute before starting and occasionally during long runs, when the throttle is not shut off for a considerable length of time. Except for this, one drop of oil to the intercepting valve every four or five minutes is ample when running.

Besides the intercepting valve, the other parts of the American articulated compound locomotive that should be oiled, which are not found on the ordinary locomotive, are:

Sliding boiler bearings on the front engine,

The ball joint in front of the high pressure cylinder (*before starting on a trip*),

The upper or rear ball joint of the exhaust pipe (*before starting on a trip*),

The lower or front ball joint of the exhaust pipe (*before starting on a trip*),

The bolt connecting the two engines,

The ball bearings of the vertical suspension or "trim" bolts which connect the upper rails of the front frames with the lower rails of the rear frames.

The ball bearings of the floating columns (if applied),

The piston rod packing of the cylinders of the power reversing gear,

The air cylinder of the power reversing gear, by means of the plug in the top of the cylinder (*about once a week*).

Precautionary Notes.—Locomotives engaged in shifting or switching cars in yards should be moved carefully and severe shocks should be avoided when couplings are being made, as the cars or lading may be damaged, and the trainmen and others about them injured. In this service it is also important to give a distinct signal with the whistle or bell before every movement of the engine, in order to warn in time

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those who may be standing on the track in the way of the locomotive or cars or engaged in loading, cleaning or repairing cars, and thus give such persons ample time to get out of the way.

If from any cause the water becomes low in the boiler, the fire should be quenched before the water gets below the highest point of the crown sheet. This can be done most effectually by dropping the dump grates and knocking the fire out; the temporary increase of heat occasioned by the act of knocking out the fire is sometimes undesirable, and so in such circumstances the safest plan is to dampen the fire by throwing upon it wet earth or wet fine coal, or drenching the fire with water.

If necessary to draw the fire on an engine that is to be moved or stand in an unprotected place in cold weather, no water should be left in the tender, boiler, lubricator, or any of the pipes.

In cold weather care must be exercised to prevent water freezing in supply pipes to injectors, tenders, steam heat pipes, track tank scoop if applied, and air pumps when not running. To prevent water in supply pipes and tender freezing convert injector into heater as explained in Injectors, Part V. Steam heat pipes can be kept open by breaking joint of steam heat train pipe valves and allowing circulation of steam. Track tank scoops are usually provided with special steaming connection for preventing freezing. In severely cold weather air pumps should not be shut off entirely, but allowed to run slowly, which may be provided for by allowing the escape of air through partly opened angle cock.

When leaving a locomotive at a terminal or any point, unless some one takes immediate charge, the following precautions should be taken to prevent it inadvertently moving: It should be observed that throttle valve is shut, reverse lever placed in center notch, cylinder cocks opened and the tender hand brake set. If necessary to further secure the locomotive, blocks may be placed each side of a driving wheel.

Running Shay Geared Locomotives.—The gear rims are held to driving wheels by several turned studs, fitted to reamed holes, having a nut and key on the outer end and two nuts on the inner. There are also two keys between gear rim and driving wheel to take the shear.

The studs must be kept tight. The lock nuts are put on them inside, so that by getting under engine it is possible to tighten all studs without moving engine.

If the gearing meshes too deeply, so that gear teeth *bottom,* place sheet iron liners back of line shaft brasses, thus moving the pinion out from gear rim. If teeth do not mesh deeply enough, make sure first that there is not too much end play of axle. Then take out liners back of line shaft brass (if any are there) until teeth mesh to the proper depth.

The pinions are bored and keyseated to standard size, and are

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pressed on line shaft by hydraulic press—the pressure varying with the size.

Be sure in adjusting line shaft that you keep both boxes the same height above rail and same distance out from wheel. Keep the boxes in adjustment so that shafting turns easily in boxes without binding.

If the center plates are allowed to wear badly and get rough, it is well to put in a liner from 1/4" to 3/8" thick, or sufficient to give proper clearance of side bearings, or to order new center plate castings.

If the axles get too much end play it may be taken up by putting sheet metal liners behind end bearing brass in left truck box.

If for any reason it is desired to turn the wheels and axles end for end, the wheel centers on left hand side are all drilled and key seats prepared so gears may be put on without difficulty.

The crank bearings should be kept up as close to the crank shaft as possible without cramping it. Crank shafts never break from being twisted off—they break only because bearings are not kept in line.

The center of the axle and line shaft should be nearly same height above the rail. If by wear of the journal brasses the line shaft center line falls more than 1/16" below axle, place shims of sheet iron above journal brass till axle center line is about 1/16" low; this will allow for a little wear before another lining up is needed. If the middle bearing on a three-cylinder engine is allowed to get out of line with the end ones the strain on the crank shaft is more than doubled.

End play of line shaft may be taken up by inserting washers in halves between the cast iron washer and collar.

The following bearings should be oiled at least once a day and as much oftener as the demands of the service require: crank shaft bearings, main rods, guides, center plates, coupling ring, bolster end castings, journal bearings, line shaft bearings, line shaft collars, square shafts, sleeves, piston rod and valve stem packing.

The gears and pinions should be lubricated with coal tar or pine tar mixed with oil. Lubricate gears and pinions frequently and keep gear covers in place.

FIRING.

A very common yet important natural change of material condition is the process known as burning, and to properly comprehend the nature of this interesting process requires a rudimentary knowledge of the laws of combustion. In its broadest sense combustion means any chemical act that is accompanied by light and heat, but ordinarily it means the union of fuel substances with oxygen of air. In Part III we say that matter is divided into invisible particles called atoms and molecules; that molecules are combinations of atoms held together by force of some kind; that these molecules revolve around

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one another at a great velocity, the rate of which is affected by temperature conditions; that molecules composed of two or more elements are termed compounds; that atoms of each elementary substance combine with others in proportions definite and invariable, though the proportions vary for different elements, and that some elementary substances combine with others in more than one proportion, but each combination produces a specific compound differing from each of the others. An example of this last statement, which is of great importance in connection with fuel combustion in locomotive fireboxes, is the well-known fact that carbon and oxygen combine in at least two proportions.

Great affinity exists between atoms of combustible substances and oxygen, and when excited into activity by the application of heat these atoms rush together, producing molecular motion of enormous velocity. This high rate of motion is recognized as high temperature, and the rushing together of the atoms is termed combustion. Most substances must be heated to a high temperature before they will combine with oxygen. Every fuel substance has its kindling or igniting temperature —*i.e.*, a point of temperature at which it will unite with oxygen. Below this temperature it will not unite, and combustion cannot be effected.

The igniting temperature of carbon alone is about 1650° Fahrenheit. An experienced person can with the unaided eye estimate the approximate temperature of a fire or hot body by observing its color. A fire just visibly red has a temperature of 977°; a clear cherry red 1832°, and a bright white heat about 2550°. Thus it is apparent that color is a true indication of a fire's condition. Recently conducted tests of a thorough and comprehensive character have demonstrated that locomotive firebox temperatures range between 1400° and 2300° Fahrenheit.

Tests have also proved that to burn one pound of average bituminous coal there is required the oxygen contained in eleven and one-half pounds of free air. As one pound of air occupies thirteen cubic feet of space there is required one hundred and sixty cubic feet of air for each pound of coal burned. In fact, even more, for under practical conditions obtained in locomotive fireboxes, a surplus of air must be admitted to a fire in order to insure the requisite supply of oxygen, so that not less than twenty pounds or two hundred and sixty cubic feet of air is needed for each pound of coal.

The average bituminous coal is composed of about 60 per cent. carbon, 30 per cent. volatile or gaseous matter, and 10 per cent. non-combustible matter. The volatile matter, known as hydrocarbons, is a compound of hydrogen and carbon chemically united; it requires high temperature to ignite it, and when burning generates intense heat. The fixed or free carbon that is left in the form of coke after

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the volatile matter has been distilled burns either wholly in the solid state or part in the solid state and part in the gaseous.

The process of combustion in a locomotive firebox is rapid, for a characteristic feature of their construction is the relatively small fire grate area, and so it is usually impossible to furnish sufficient air at the proper temperature to obtain perfect combustion of the volatile matter. The gaseous products of combustion frequently flow through the tubes at a velocity of thirty miles an hour. If the grates are obstructed by a heavy fire, clinker or other matter, the passage way to the firebox will be restricted and the required amount of air will not be admitted to the fire, resulting in the passing away of unconsumed gases and consequent loss of heat.

When a charge of coal is applied to a fire the hydrocarbons are quickly expelled. At 1800°, a temperature corresponding to a clear cherry red, the combination between the hydrogen and carbon is broken down and the carbon freed in the form of an impalpable powder. At this temperature, if there is present sufficient oxygen in touch with these fuel elements they will both burn. If the disengaged carbon is not supplied with sufficient air or is cooled below the igniting temperature, as by coming into contact with the comparatively cold heating surfaces of a steam boiler, combustion is arrested and it passes off as smoke. But if mixed with the requisite quantity of air and heated to the igniting temperature the mixture burns, complete combustion is effected, and the resulting product of combustion passes off as a colorless vapor.

In a previous paragraph of this Part it is mentioned that carbon and oxygen chemically combine in at least two proportions, and the importance of this fact in its relation to fuel economy cannot be overestimated. For 12 parts of carbon and 16 parts of oxygen, by weight, combine, forming *carbon monoxide* (*CO*), while 12 parts of carbon and 32 parts of oxygen combine, forming *carbon dioxide* (CO_2). One pound of carbon burned to carbon dioxide, CO_2, generates 14,500 heat units, while in the formation of carbon monoxide, incomplete combustion, only 4400 heat units are produced. If the passage through the grates is restricted by a too heavy fire, a bed of clinker, or insufficient air admission from any cause, the formation of carbon monoxide, CO, which is imperfect combustion, is likely to result, generating less than one-third the amount of heat produced by complete combustion.

The most important ends to be obtained in locomotive firing are: First, generate steam enough so that the locomotive can perform the work required of it; second, the requisite quantity of steam should be made with the least consumption of coal, and, third, smoke emission should be reduced to a minimum. The last feature has lately become the most important one in connection with locomotive firing, as most cities and towns have laws prohibiting the emission of smoke. At least

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these laws usually put a limit on the density and period of time that smoke may be emitted from locomotives. The railroad companies themselves have regulations prohibiting the emission of smoke about passenger stations, and while passing through tunnels and under bridges.

Firing Bituminous Coal.—There are several methods of firing practised. Among them are level, bank, and a method of firing wide firebox locomotives in which most of the coal is placed along the sides and back end of the firebox, allowing the center to burn bright, getting its supply of fuel from the thick bed around the sides and back. It is generally conceded that a medium fire of uniform thickness gives the best results, or of such thickness that the fire will burn with a white blaze, and firemen should thoroughly comprehend that the process going on in the firebox is the combining of atoms of carbon and hydrogen with those of oxygen, and that the color presented by the blaze is a true indication of the thoroughness of combustion.

As large quantities of coal placed on the fire at one time liberate proportionate volumes of gas, it naturally follows that the greatest economy of fuel with least smoke discharge can be obtained only by applying small quantities of coal at regular intervals; for extremely heavy or rapid firing—*i.e.,* several shovelfuls of coal placed on the fire at one opening and closing of the firedoor is wasteful of fuel and its effects on firebox sheets are also destructive. It lowers the temperature of the firebox, which produces excessive smoke and contraction of firebox sheets and tubes, resulting in cracked sheets and leaky tubes. Localized, heavy firing produces more clinker than a uniform evenly burning fire, as such fires burn through in spots, having a sort of blow pipe action that generates intense heat, and if the temperature is higher than the fusing point of clinker-forming substances these melt and form clinker.

Clinker-forming substances are associated with solid matter of coal and consist of silicates and pyrites, which at very high temperature fuse. This molten matter percolates the fire and mingling with the comparatively cold ashes on the grate cools, solidifying the mass into cakes of hard matter.

The draft produced by the exhaust ceases when locomotive is running with the throttle valve closed, the amount of air passing through the fire is proportionately reduced, and excessive smoke will be emitted unless proper precautions are taken. Prior to the closing of the throttle the fireman should stop firing in time sufficient to allow greater part of gases to be consumed, and just before throttle is closed the fire door should be partly opened and the steam blower applied and remain so until the shutting off of blower or closing the fire door will not result in smoke emission.

Coal should be broken into sizes not exceeding three inches in

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diameter, should be properly wet and distributed as evenly as possible over the bright places in the fire. However, too much water on the coal to be placed on the fire should be avoided, as to some extent this practice is the cause of the flues becoming stopped up.

What is termed the *one shovelful* method of firing is a required practice on some railroads, which means placing the shovelfuls of coal on the fire at equal, regular intervals of time, consistent with the work the locomotive is performing, allowing the fire door to remain partly open after each shovelful, to permit air admission over top of the fire, until the gases have been consumed and shutting the fire door will not result in smoke emission. Where its practice meets steam requirements of the locomotive, it is commendable, for it is a very efficient system of firing; but large locomotives consume such great quantities of coal as to necessitate very rapid firing, and it is impracticable to allow the fire door to remain open for a period of time after each shovelful of coal. Locomotives working at the limit of the boiler's steaming capacity frequently consume coal at a rate of 150 pounds the square foot of grate an hour, aggregating in modern locomotives a total quantity of 6000 to 8000 pounds in the same time, and so in order to maintain the fuel bed under such conditions firing must be so rapid that refinements of practice must be sacrificed.

Firing Anthracite Coal.—Anthracite coal burns more slowly than bituminous coal, from which it differs in that it contains more carbon and less hydrogen, and in consequence but little gas is given off and practically no smoke emitted during the process of its combustion.

Anthracite coal-burning locomotives have a larger grate area provided than those burning bituminous coal, for there are practically no heat-producing gases to be burned, and a greater amount of fixed carbon must be burning at one time than with bituminous coal, so as to generate as much steam. The early anthracite coal-burning locomotives had long, deep fireboxes, but now nearly all have very wide fireboxes of large grate area of the Wootten or modified Wootten types.

Good judgment is required to regulate the thickness of a fire of anthracite coal, the thickness depending on the quality and grade of coal to be burned. The larger the lumps, the thicker must be the fire carried, so as to prevent the admission of excess air to the firebox lowering its temperature, for the larger the lumps the greater the air space between them.

In firing anthracite coal the admission of air above the fire is not of such importance as when bituminous coal is being burned, and fairly good combustion can be secured with the air admitted through the fire, as there are practically no gases to be burned. There is a tendency for air passages or holes to form close to the sheets, especially with the small grades, and to provide against this the fire should be carried heavier close to the sheets than in the middle of the grate.

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When too much air is admitted through the fire, tendency is to reduce the firebox temperature below the igniting point, while on the other hand if the supply of air is restricted, as when carrying a heavy fire with the small grades of coal, combustion will be incomplete, the following taking place: The intense heat near the grates will cause the oxygen of the entering air to combine with the carbon of the coal and form carbon dioxide (CO_2); but as this passes upward it combines with another atom of carbon and forms carbon monoxide (CO), which passes off unburned as an invisible gas.

The wide firebox types usually burn the small grades of coal, such as buckwheat, rice, and also a mixture composed of culm and soft coal, usually mixed in proportions of from three to five tons of anthracite culm to one ton of run-of-mine bituminous coal.

The fire in this type of firebox should be built up a little heavier than ordinary before leaving a terminal, so that the fire can be left alone while it is "bedding" itself. When the fire becomes properly bedded the firing can proceed in about the same manner as when firing soft coal. The grates should be shaken only when necessary to keep the fire clean, as it is poor practice to disturb the bed of fire.

The secret of successful anthracite firing is to keep the grate near the sheets well covered, watch for and prevent the formation of air passages, caused by dead spots or thin places in the fire, through which large quantities of air can pass. The fire must be kept in good condition, for anthracite coal will not "catch" fire unless the conditions are right. A shovelful of bituminous coal can be used to fill a hole in a bituminous-coal fire, and the heat of the surrounding fire will ignite it; but it is not thus with anthracite coal; there must be fire under the fresh coal or it will not ignite, and so a hole in an anthracite-coal fire must first be filled with live fire and then covered if it is expected that the covering will ignite.

When the mixture of anthracite and bituminous coals previously mentioned is burned in wide firebox locomotives, it is fired about the same as bituminous coal. The bituminous coal may be used to bed the fire when starting out, and some of the lumps may be saved to fill up holes, or to more quickly regain the required steam pressure should it for any reason become low.

The Wootten firebox as originally built had a combustion chamber between the firebox and the back flue sheet and was provided with a bridge wall of brick at the back end of combustion chamber. Most wide firebox anthracite coal burning locomotives of the present time are of the modified Wootten type and are not provided with combustion chambers.

Notes—Both Kinds of Coal.—Firemen should observe engineers in the work of operating locomotives and give immediate attention to their instructions. When advised in advance of a change in running

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conditions that will increase or decrease the amount of steam required they should immediately prepare their fire to meet these conditions. They should so fire locomotives as to enable engineers to maintain a practically uniform height of water in the boiler, though at the same time avoid as far as practicable waste of steam at the safety valves.

When running with the throttle valve closed, a good bright fire should be maintained, especially at the front end of the firebox, as dead spots in the fire are frequently the cause of tubes leaking.

As a matter of cleanliness, the sprinkling hose should be used frequently to keep down dust on the deck and in the cab, and to wet coal in the tender, and coal should not be allowed to collect or remain on the deck, but should be swept in the coal space of the tender and not on the tracks.

The grates should be shaken as frequently as is necessary to clear the fire of ash and clinker, and in such manner as to avoid the loss of good fire. Care should be taken to place the shaking grates level after each operation.

The safety valves on locomotives carrying 180 (or more) pounds steam pressure when open will blow out of the boiler about 75 pounds of water per minute; this in turn will make necessary placing on the fire one additional shovelful of coal per minute. Therefore preventing waste of steam through safety valves will effect the saving of much labor, coal and water.

Locomotives should not be taken to engine terminals with fire, either too heavy or partly out, as the former results in waste of fuel and the latter may cause tube leakage.

The fire should be kept bright when the boiler is being fed with water. If throttle is closed at this time the blower should be applied in order to keep the fire bright and the water circulating in the boiler. The fire door should never be kept open for a great length of time, or the fire cleaned or banked while the injector is in use.

Firing Oil.—A fire pan is substituted for the grates in oil-burning locomotives, being located in the bottom of the firebox, and is lined throughout with fire brick. The front end of the fire pan proper is some distance back of the front water leg, and the intervening space is bridged over by a steel plate covered with fire brick. The draft is controlled by a damper that is placed in the front end of the fire pan. Provision is made for admitting air above the fire through the fire door.

The supply of oil is carried in oil tanks located in the pit of the tender. Before being injected into the firebox it usually must be heated, which is accomplished by a coiled steam heating pipe passing through the oil tank. The proper degree of temperature to which the oil should be heated to obtain the best results depends upon the thickness of the oil. The thickest kinds should be heated to a temperature

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of from 150° to 160° Fahrenheit, and the thinner oils to 100° to 120° Fahrenheit.

The burner resembling a simple injector has a pipe connecting with the oil tank, the connection being a short distance above the bottom of the tank in order to avoid conveying water with the oil. In addition to the oil pipe there is an air pipe and also a steam pipe connected to the boiler and all so arranged that when the valves with which the pipes are fitted are opened the jet of steam will project a spray of oil against the flash wall.

In starting the fire in oil-burning locomotives it is necessary that steam or compressed air be available. After greasy waste or other inflammable material has been placed in the firebox and lighted the valves should be opened slowly and the oil will readily ignite. As there is usually some water in crude oil there is danger of a newly started fire going out and the oil may, if permitted, continue to run into the firebox before the brickwork has been sufficiently heated to reignite the oil. The fact should be carefully noted, as the accumulation of oil in the pan might cause a serious explosion while reigniting. The quenching of the fire by the mixture of water may readily be detected by the appearance of white smoke coming from the smoke stack and also from the odor arising from the oil on the partially heated brickwork.

When firing up when there is no available pressure, wood must be used in the usual way to raise a pressure of steam. Care should be taken not to damage the brickwork by carelessly throwing wood into the firebox. While the draft appliances are the same as in coal-burning locomotives, there is no netting or spark-arresting device, the omission of which necessitates care when the wood fire has sufficiently heated the water so that a pressure of steam may be applied to the oil-burning device, for a shower of sparks may be thrown from the stack and it is well to observe there is no inflammable material in the vicinity. The burning of oil has a tendency to deposit a gummy substance on the firebox ends of the tubes, and even with proper firing and no appearance of smoke soot accumulates in the tubes. This can be remedied by an occasional application of sand, which is admitted into the firebox through an elbow-shaped funnel inserted through an opening in the firebox door. When sand is being admitted for this purpose the engine should be running with long stroke of valves and the throttle opened wide, the severe draft drawing the sand through the tubes with such velocity that the gum and soot will be cleaned with a few blasts.

The secret of successful oil firing is the proper manipulation of the oil supply valve, which is as important as the manipulation of the throttle and reverse lever in the control of the locomotive, and in fact must be skilfully worked in harmony with them.

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PART IX

DISORDERS

Deterioration, Pounds, Blows, Breakdowns

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DETERIORATION.

Deterioration of the various constructional parts of a locomotive begins at the very outset of its service, and some parts wear so rapidly that, unless repairs, renewals or necessary adjustments are promptly made to worn parts, disorders that will result in a locomotive failure on the road are inevitable. In the early days of railroads failures were very frequent owing to inferior material or lack of requisite strength and to primitive design; but failures of modern locomotives serious enough to cause disablement are comparatively few, for in the process of the locomotive's development, design has improved so as to better meet stress and shock, and material more reliable and of greater strength has been evolved and adopted in locomotive construction.

Engineers are required to possess enough mechanical ability and knowledge of a locomotive's construction to enable them to disconnect the disordered parts of a disabled locomotive, or improvise some temporary expedient, so that it can run to a terminal under its own steam, if practicable, with reduced train tonnage, if necessary, eliminating possibility of further damage. Methods of disconnecting and rules of procedure to meet nearly every contingency in locomotive operation have been discussed, written up and those proving successful authoritatively established as correct practice.

Information relating to this feature of railroading has become almost a science, and firemen are required to pass a satisfactory examination in its principles before they can become engineers. However, there is a growing tendency in present practice to deviate somewhat in detail from the old established methods of disconnecting disabled locomotives, though the requirements of engineers and firemen undergoing examination for promotion are just as exacting as ever, so far as knowledge and ability are concerned.

There are several reasons for the change of methods: Some of the reciprocating parts of modern locomotives are so heavy that engineers cannot handle them; tool equipments have been pruned till they just meet the bare needs of normal working conditions; shops and locomotive terminals, or points where spare locomotives may be obtained, are greater in number; wrecking trains equipped with suitable tools and apparatus for making temporary repairs or arrangements of such character to disabled locomotives that they can promptly proceed or be moved from main tracks out of the way are at convenient places; and, most important of all, traffic has become so dense on nearly all railroads of importance that stops out of ordinary are almost sure to result in detentions or cause serious congestion. The greatest change

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that has taken place is in connection with the removal of main and side rods, though removal of main rod simply because of disconnecting valve stem and covering ports with valve has become so rare that it seems hardly necessary to make it a subject of discussion here.

The established practice in regard to disordered side rods has been: *In case of failure necessitating removal of side rod or section of side rod the corresponding side rod or section of side rod on opposite side should also be removed.* And, *in case of failure of front section of side rod on locomotives having three pair, or of intermediate section on those having four pair of connected wheels, remove all side rods on both sides and run locomotive with only main rods connected.* Another, *in case main crank pin breaks off close to wheel center, remove all side rods on both sides and run locomotive with but one main rod connected.*

The first proposition is undoubtedly the correct method when the side rod involved is either a front or back section on any type of locomotive with four pair of connected wheels (Mallet types with two groups included), and back section of types with three pair connected (Mallets included); but when a disorder necessitates the removal of all side rods on the disordered side of a locomotive, there are circumstances in which it may be much better practice to allow the side rods to remain connected on opposite side. The removal of side rods on both sides of a locomotive reduces its available adhesion in proportion to the number of drivers remaining connected, that is, if side rods were removed from both sides of a 4–4–0 or a 4–4–2 type the adhesion would be reduced about one-half; if removed from both sides of a 2–8–0 type it would be reduced to one-quarter. With adhesion reduced to such low points locomotives could not satisfactorily handle trains owing to excessive slippage.

It has been satisfactorily demonstrated that where a disorder necessitates removal of all side rods on one side, under ordinary circumstances the best method of procedure is to allow side rods on the opposite side to remain connected, and that such practice results in saving in time required to disconnect the disordered parts, gives more satisfactory road performance and enables a locomotive to handle a heavier train than if all side rods are removed, though it must be remembered proper precautions must be taken when this method is followed. In all cases when this method is followed *the main rod must be removed on the disordered side, or at least the engine on that side must be put out of commission by disconnecting the valve stem and covering ports with valve.*

The reason for putting engine on disordered side out of commission is so that the drivers will not slip when the crank pins on connected side are on the center, straining or buckling the side rods. This is the only point where a straining action on side rods would have a tendency

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to buckle them, which might occur by one pair of drivers slipping and the others not slipping in unison, but if the engine were out of commission on disordered side there would be no tendency to slip when the connected side was on the center, for the engine on its center could not exert this tendency. Besides, if one engine of a locomotive were out of commission its tractive effort would be reduced one-half, which would double the adhesion, lessening the tendency to slip.

However, in the matter on "Breakdowns," later on in this part, the old established practices are outlined as a guide in case of disorder; though literal compliance with some of them by a locomotive crew single-handed is simply impracticable on modern, large locomotives, particularly those in connection with broken axles and broken tires. In giving these notes on breakdowns the purpose in view is not so much that such method of procedure should be rigidly followed as to show what can be done where circumstances warrant under certain conditions with requisite facilities, and also to serve as a course of study for engineers and firemen required to pass examinations in such subjects.

POUNDS.

The nature of work that locomotive engines perform prevents them operating noiselessly, so that the smoothness of their action can never compare favorably with properly constructed stationary engines of good design; but the connections and reciprocating parts of a locomotive that transmit power should be free from pound or shock, if they are rightly proportioned, skilfully put together and properly maintained. Enormous stresses are produced in the reciprocating connections of large locomotives by alternately applied forces of steam under normal conditions, but when lost motion develops in these connections or in the frame splices shocks are produced that cause rapid deterioration of the machine, even to the extent of loosening firebox staybolts and opening boiler seams with consequent leakage, hastening the time of shopping for general repairs, if not resulting in actual breakage of some important part. Pounds are not only destructive to the entire locomotive, but the resulting shock is extremely annoying to engine crews and really has a tiring effect. When from any cause they arise the engineer should locate them, remedy them or have them remedied; not only to maintain the efficiency of the locomotive, but also to add to the comfort of those required to ride on it.

Pounds about locomotives are usually owing to the following causes: Lost motion between driving boxes and pedestals, between brasses and main pin or brasses and cross-head wrist pin, in back and front ends of main rod, and between cross-head and guide bars; piston loose on

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piston rod, or piston rod loose in cross-head; broken frame; loose frame splice; cylinder loose on frame, and lost motion in firebox expansion pads or braces.

The working of driving boxes up and down in the pedestals wears the faces of boxes and shoes, resulting in lost motion. As this lost motion develops the wedges should be adjusted. When after repeated wedge adjustment the wedge bolt is at its extreme height the wedge should be dropped and liners of required thickness placed between shoe and pedestal, and the wedge readjusted. This is engine-house work, and when necessary engineers should report *line down wedge.*

Lost motion between driving axle journal and driving box bearing, owing to wear of journal or bearing, is another source of pounds. The only remedy for this disorder is for the wheels to be dropped, and the bearing refitted to the journal.

Lost motion between brasses and pins in main rods is usually the result of wear, though sometimes it is caused by improperly adjusted keys. The practice has become almost general to fit brasses of both ends of main rods so that they will be *brass and brass* and have a clearance on the pins. This is done for two very good reasons: First, it prevents the brasses being keyed so tight as to clamp pins, as could be done with brasses fitted on pins *open,* resulting in heating main pins and heating or loosening cross-head wrist pins. Second, hard grease compound is now generally used for pin lubrication, and, as bearings lubricated by grease properly run warm, more freedom than when oil is used is required between brasses and pins to permit expansion.

The rods and brasses of large, modern locomotives are so heavy and large that it is impracticable, in fact, almost impossible, to adjust them with the same nicety that obtained with the smaller locomotives of a few years ago, and on locomotives in pool service, as most locomotives of the present time are, fitting them in any other way would surely result in trouble, and so the practice of fitting brasses with clearance seems the best. It is the practice on one railroad to fit main rod brasses, front end, so as to just barely clear the pin when "brass and brass," and with 1/32 inch clearance in back end brasses. If brasses are fitted with clearance engineers should make sure that keys are adjusted tight. When excessive lost motion develops owing to wear then the brasses should be filed, and the engineer should report *file out brasses,* naming the brasses requiring attention.

Side rods pound very little unless the brasses or knuckle joint connections are very much worn, or driving axles are out of tram. Worn side rod bushings and knuckle joint connections produce considerable noise by rattling, however.

In replacing brasses, when making repairs that necessitate main rod removal, shopmen sometimes carelessly line brasses too far ahead

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or too far back, allowing over-travel of piston and possibly piston striking cylinder head, resulting in a pound. This condition can be detected by observing cross-head travel on guides, noting whether the cross-head over-travels at back or front ends of guides.

Lost motion between cross-heads and guides can be remedied by closing guide bars, renewing or rebabbitting cross-head shoes, depending on form of construction. Too much lost motion between cross-head and guide bars may result in a bent piston rod. Where babbitt metal is used as a cross-head shoe bearing, it should be noted when this has worn off, and engineer should report *rebabbitt cross-head shoe.*

Broken frames, loose frame splices, or loose cylinders, cause pounds that usually jar the entire locomotive. With any of these disorders it is usually necessary to detach locomotive from train, if it has one, and run it light to shop for repairs, though it might be practicable to haul train to a point where another locomotive can be secured, working the disordered one at reduced speed and capacity.

Lost motion in firebox expansion pads or braces produces shocks that differ somewhat from ordinary pounds. The back end of boiler works sideways or up and down, or both, on the frame, and if allowed to continue for considerable time will cause loosening of bolts in cylinder saddle and smoke box connection, resulting in leaky steam pipe joints. It also frequently causes breakage, or jars loose unions, of air and water pipes attached to the back head of boiler or attached jointly to back head and that part of locomotive rigidly attached to frames. The remedy for this disorder is to insert liners between worn pads or refit bolts in braces.

To test for source of pounds, place crank pin, of side to be tested, on top quarter, allow cylinder cocks to remain closed, admit small amount of steam to cylinders and work reverse lever back and forth. At the same time have some one on the ground observe parts of locomotive where lost motion may develop, causing pounds. In this manner driving boxes working in pedestals, or driving axle journal working in box, lost motion in rod brasses, knuckle joint pins working loose in jaws of side rods, loose cross-head wrist pins, piston rod loose in cross-head fit, lost motion between cross-head and guides, frame splice working loose, broken frames and cylinders working loose on frame may readily be detected. On very large locomotives the reverse lever may work so hard as to make this method of testing for pounds impracticable. The next best method is to have the observer walk alongside the locomotive when it is moving slowly and working hard. A loose piston on piston rod cannot be detected by either of these methods, and if there is reason to suspect a disorder of this character the cylinder head should be removed and an examination made.

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BLOWS.

Internal blows, such as result from broken or badly worn cylinder packing rings, defective pistons, worn cylinder bore; worn or broken valves, valve seats or valve bushings; improperly fitted balance strips, springs broken under them or balance strips stuck down, are noticeable irregular sounds. These sounds usually can be heard emanating from the stack, though sometimes they are not of sufficient volume to be heard at the stack, but may be distinctly detected by listening at the open fire door while the locomotive is working.

Blows produced by defective cylinder packing or worn cylinder bore usually make a peculiar wheezing sound just after each exhaust. If the cylinder packing rings are either broken or worn out they no longer make a steam-tight fit against the cylinder walls; consequently, the steam admitted alternately into each end of the cylinder can flow by the defective packing rings into the opposite end of the cylinder, which is open to exhaust, and out through the exhaust, producing not only a blow but causing loss of steam, fuel, and also impair the efficiency of the locomotive.

To make a test for cylinder packing or cylinder blows place crank pin on quarter, set brakes, open cylinder cocks, with reverse lever in full gear admit steam. If steam escapes at both cylinder cocks it is an indication that steam is blowing by the piston, provided there is no leakage at the main valve. Defective cylinder packing can also be detected while the locomotive is working steam, by the character of the sound, as it blows hardest at the beginning of the stroke and gradually decreases as the stroke is completed.

Loose rings on built-up pistons cause a peculiar kind of blow, as the blow occurs only as the piston is moving forward, and the locomotive will have three clear exhausts and a blow with the fourth per revolution. The reason for this is that steam admitted behind the piston forces the loose ring away from its center, passing through the defective joint, and when steam is admitted to the front end of the cylinder the ring is forced back to its place on the center, making a steam-tight joint. To detect a loose piston ring while running, watch the cross-head and if the blow occurs when cross-head is leaving back end of guides on one side—but not when leaving the front end on same side—it can generally be attributed to loose piston ring. To make a standing test, place crank pin on quarter, set driver brakes, place reverse lever so as to admit steam back of piston, open cylinder cocks, admit steam and notice if steam comes out of both cylinder cocks; then place reverse lever so as to admit steam in front of piston and again notice escaping steam from cylinder cocks. If the blow occurs and steam escapes from both cylinder cocks when steam is admitted back of piston, and the blow ceases and steam escapes from front cylinder

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cock only when steam is admitted in front of piston, it is almost a certainty that the piston has a loose ring.

Slide valve blows are usually caused by worn or cut valve face, valve seat, balance plate or defective balance strips. When these parts are cut it is usually caused by insufficient lubrication, sometimes owing to the lubricant being washed from the bearing surfaces by water carried into the steam chests with the steam.

Piston valves do not develop blows as frequently as slide valves, as the usual disorder with them is defective packing rings, which rarely are serious. If inside admission piston valves are fitted with two rings at each end, the inside rings govern the admission of steam and the outside rings the exhaust of steam from the cylinder. When an exhaust ring is broken it will cause only a lame exhaust, and very little, if any, blow will result, as in this case the exhaust merely takes place sooner than normal. If the steam ring is broken, however, it will not only cause serious lameness, but will also cause a blow when the engine is in a certain position. Steam rings can be tested the same as for slide valve test, which will be presented later; but defective exhaust rings can seldom be located by standing tests, and a running test must be depended upon to locate this defect. As before stated, in case one of the exhaust rings is broken it causes the locomotive to go lame, and also produces a very slight blow. The locomotive will have three normal and one light exhaust, and by observing the cross-head and noting on which side of the locomotive the light exhaust takes place the defective side may be detected.

To test for valve blows, place crank pin on quarter, reverse lever in center of quadrant, which will bring the valve to center of its seat, apply the brake, open cylinder cocks and admit steam. If steam escapes from either of the cylinder cocks it indicates leakage between the valve and its seat. With inside admission piston valve, proceed in the same manner, and if the valve rings are broken or worn or the bushing defective the blow will be more pronounced from the exhaust nozzle than from cylinder cocks. On the other hand, blows caused by outside admission piston valves will give a more pronounced discharge of steam from the cylinder cocks.

The preceding notes are not infallible directions for testing for internal blows, for owing to the similarity of cylinder and valve blows it is sometimes difficult to distinguish between the two. However, as blows of this character are very wasteful of steam, result in considerable loss of fuel and sometimes loss of power, their existence calls for prompt attention.

External blows, such as piston rod and valve stem packing blows, are visible, and the cause and remedy usually obvious.

There are several different causes for irregular sounding exhaust, or "lame" valves it is sometimes termed. On locomotives having long

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curved eccentric rods a common cause is the main valves become dry for want of lubrication, causing the valves to move harder than when properly lubricated, and the rods spring or bend so as to affect the regularity of steam distribution. Increasing the supply of oil to the valves or closing the throttle for an instant will remedy this difficulty.

Other causes for "lame" valves are loose rocker boxes, bent rocker arm or shaft, bent hanger, slipped eccentric, slipped or bent eccentric rod, broken valve yoke, a sprung or twisted tumbling shaft, which may allow one link to hang lower than the other and result in lame valves owing to unequal valve travel. Eccentric rods are fastened to the eccentric straps by bolts and if these bolts become loose the rod can move, resulting in irregular exhaust. Eccentrics are usually keyed to the axle on modern locomotives and so they cannot slip without shearing key.

Loose rocker boxes should be tightened by engineers, if practicable. Bent eccentric rods, rocker arms or shafts, and link hangers should be reported by the engineer for engine-house attention. A broken valve yoke usually requires the disconnecting of one side of locomotive, necessitating running to terminal with light engine or reduced train tonnage.

BREAKDOWNS.

NOTE.—In case of accidents to locomotives or breakage necessitating removal of their parts, engineers should have the removed parts placed on the locomotive or tender so that they may reach the shop along with the locomotive.

Broken Valve.—A broken valve is indicated by an intermittent or continuous blow at the exhaust, the character and intensity of blow depending on nature and extent of break. To test for a broken valve place one engine on top quarter, move reverse lever so that valve will be in mid-position, block driving wheels or apply brake, open cylinder cocks, and then open throttle slightly. If steam escapes from one cylinder cock and at the same time a blow occurs at the exhaust it indicates a broken valve. With the valve broken so exhaust port cannot be covered it is possible to remove the steam chest cover and block the steam passages with blocks of wood.

Broken Steam Chest.—Block steam passages the same as for a broken valve.

Broken Valve Seat, or Valve Bushing (Piston Valve).—The bridge of the valve seat or valve bushing (piston valve) is the part that usually breaks. Such breakage may cause considerable damage if the broken pieces become wedged in the ports and the valve strikes them, or they may drop into the cylinder, causing damage there. A broken valve, valve seat or valve bushing is indicated by irregular sound of the exhaust or a pronounced blow, and a test should be made as out-

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lined in "Blows" for valve blows. If the blow can be stopped by some position of the valve that may be found by moving the reverse lever, the valve should be clamped in such position and valve stem disconnected from valve rod. If steam is admitted to the cylinder with the valve in this position, the main rod must be disconnected, the piston moved to the end of cylinder opposite admitted steam and the crosshead blocked. If the steam is not admitted to the cylinder it will not be necessary to disconnect the main rod. In case the blow cannot be stopped and the loss of steam is not too great the engine can be run to a terminal in this condition, probably with reduced train tonnage or light.

Broken Back Motion Eccentric Rod or Strap.—Remove broken rod and strap, drop reverse lever in full forward gear if going ahead, tie the bottom of the link front and back, place a block of wood between link block and bottom of link, so that engine cannot be reversed, and proceed. If necessary to run backwards it will be necessary to remove the forward motion eccentric rod and strap, also the valve rod, and clamp the valve in mid-piston.

Broken Forward Motion Eccentric Rod or Strap.—Remove rod and strap, take off link hanger to allow link to ride on link block, and disconnect valve rod from valve stem, cover ports with valve and clamp the valve stem.

Broken Transmission Bar.—Remove the broken bar, cover the ports with valve and clamp valve stem.

Broken Transmission Bar Hanger.—Place a block of wood under the link block to raise it as high as the opposite one, remove the broken hanger and proceed. Locomotive could be run backward full stroke with blocking removed.

Broken Valve Yoke or Valve Stem, Inside the Steam Chest.—Take down the valve rod, clamp the valve stem so that valve would be on the center of the seat if yoke and stem were not broken, then take out the relief valve or plug in the front of steam chest, push the valve back against the stem and block with wood blocks, replace the plug in the steam chest and proceed with the engine on one side.

Broken Reach Rod.—If the reach rod breaks the links will drop on link block and give full travel to valves. In this case if tumbling shaft arm extends through running board, the links can be raised to a point that will give proper cut-off to enable locomotive to handle train, and block of wood placed in slot securing tumbling shaft arm. If the arm does not extend through running board a block can be placed above the link block of one link to hold the links at proper height. When necessary to run the locomotive backwards longer blocks will have to be used in order to raise the links high enough to reverse motion of valve.

Broken Link Hanger, Saddle Pin or Tumbling Shaft Arm.—The

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same course should be followed as for a broken reach rod by placing a block in the link on the disabled side. Remove all broken parts. The locomotive cannot be reversed while running, and in case the broken part is a saddle pin or link hanger the engineer should be very careful not to drop the reverse lever in full forward gear while drifting, as the blocked link on the disabled side may strike the tumbling shaft arm and a bent or broken eccentric rod or strap might result.

Broken Reverse Lever.—Proceed the same as with a broken reach rod.

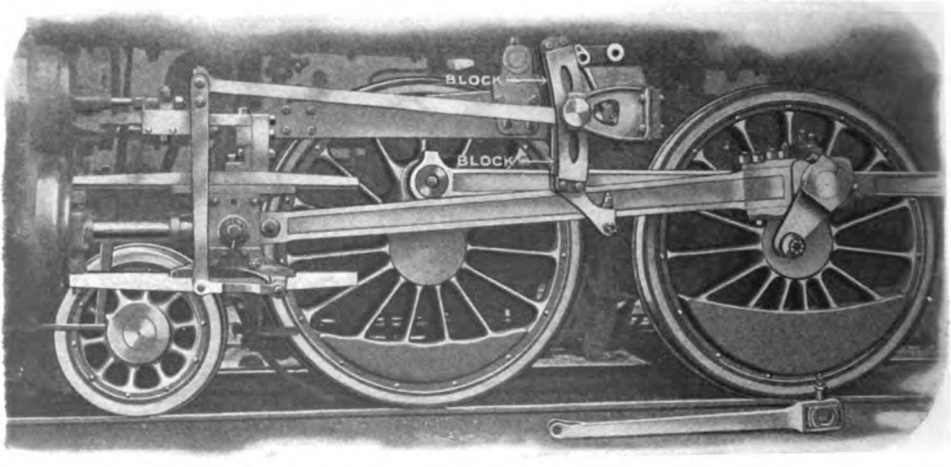

FIG. 55.—Breakdown, Walschaerts gear.

WALSCHAERTS GEAR.

If an eccentric crank, eccentric rod, or the foot of the link is broken; or one of the link trunnions twisted off, the other trunnion holding the link in position: Take down the eccentric rod, disconnect the back end of the radius rod from the lift shaft arm and secure the link block in the center of the link.

Fig. 55 shows an engine with the valve gear disconnected and blocked as just described. In the gear design illustrated the radius rod is connected to the shaft arm by means of a radius rod hanger so that it can be readily disconnected by taking out the pin connecting the radius rod hanger and the shaft arm. The link block is secured in the center of the link by means of the two blocks shown, one placed

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below and the other above the link block and securely wedged in position.

With the motion disconnected and blocked in this way the valve on the " lame " side receives a travel from the lap and lead lever equal to twice the amount of the lap plus the lead, which gives a port opening equal to the amount of the lead. This permits of leaving the main rod up and running with both sides, as the cylinders can be lubricated. The cut-off will be very short on the disabled side, but the steam that is admitted will do a certain amount of work and the engine can be reversed.

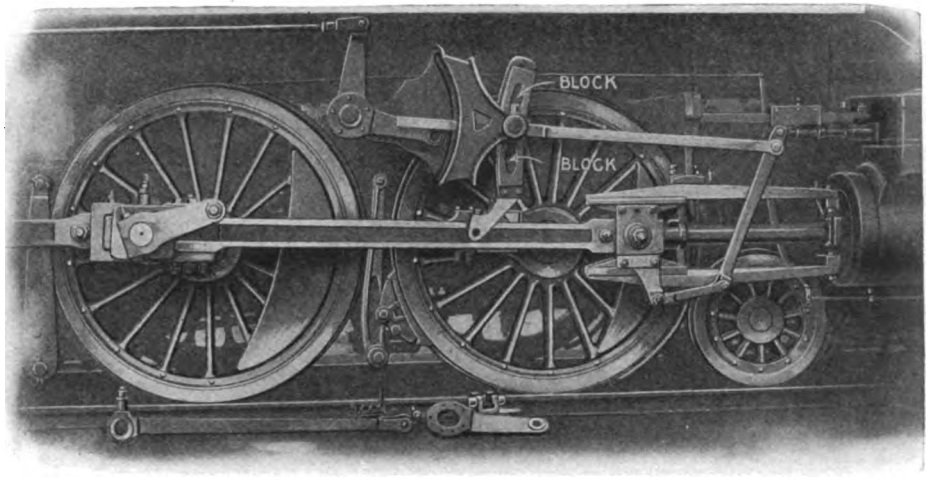

FIG. 56.—Breakdown, Walschaerts gear.

With the link block secured in the center of the link: Care must be taken in making a stop that the main pin on the disordered side is not on either quarter, as the lap and lead lever would be in a perpendicular position, the valve would be central on the seat, the pin on the other side would be on the dead center, and it would be impossible to move the engine.

In some designs of Walschaerts valve gear the radius rod is directly connected to the lift shaft arm by a slip block or crosshead. It is common practice in such cases to make the lift shaft arm in two pieces so that the radius rod may be easily disconnected from it, as shown in Fig. 56. Remove the outer section of the lift shaft arm, take off the cap of the slip block, lift out the end of the radius rod and remove the slip block. The parts necessary to remove are shown in the foreground. The link block is secured in the center of the link in the same way as in the previous case.

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For disorders requiring the blocking of the valve to cover the ports such as broken main rod, bent piston rod or cylinder head knocked out: If the valve has inside admission and there are no relief valves in the cylinder heads, the engine may be disconnected and blocked as shown in Fig. 57. Disconnect the front of the radius rod from the lap and lead lever and suspend it clear of the latter by means of a wire or chain from some convenient support. Secure the valve to cover the ports. This can usually be done by means of the set screw provided in the valve stem crosshead for this purpose; but, if there is no such set screw, the valve stem crosshead may be blocked.

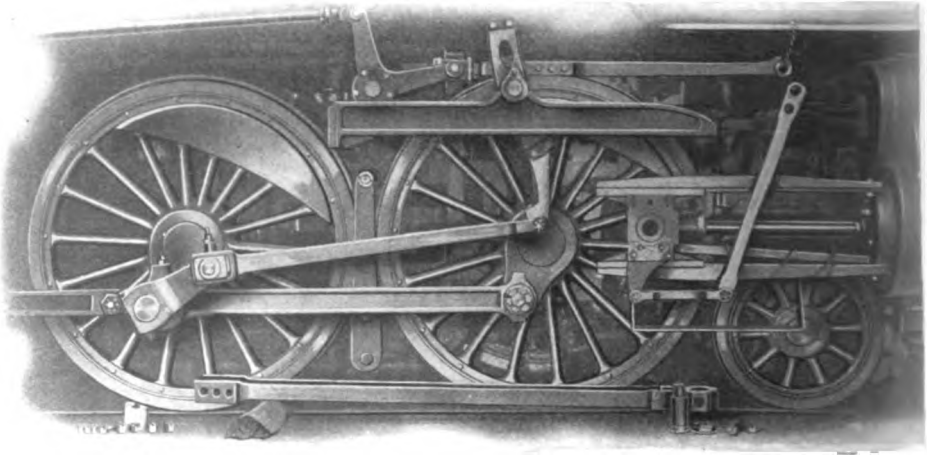

FIG. 57.—Breakdown, Walschaerts gear.

With the valve gear disconnected in this way the reverse lever is free to operate the other side, and the engine can be run with one side. If the crosshead arm, lap and lead lever connector, or lap and lead lever is broken the engine might be blocked in the same way as illustrated in Fig. 57; though such of the broken parts should be removed as would interfere with the running of the engine. If necessary to remove the main rod, block the crosshead at the back end of the guides as shown.

If the valves have outside admission and there are no relief valves in the cylinder heads when necessary to secure the valve to cover the ports, the engine might be disconnected as shown in Fig. 58. Disconnect the radius rod from the lap and lead lever and remove the latter, so the front end of the radius rod will not strike the lever as the radius rod moves back and forth to the motion of the link. Suspend

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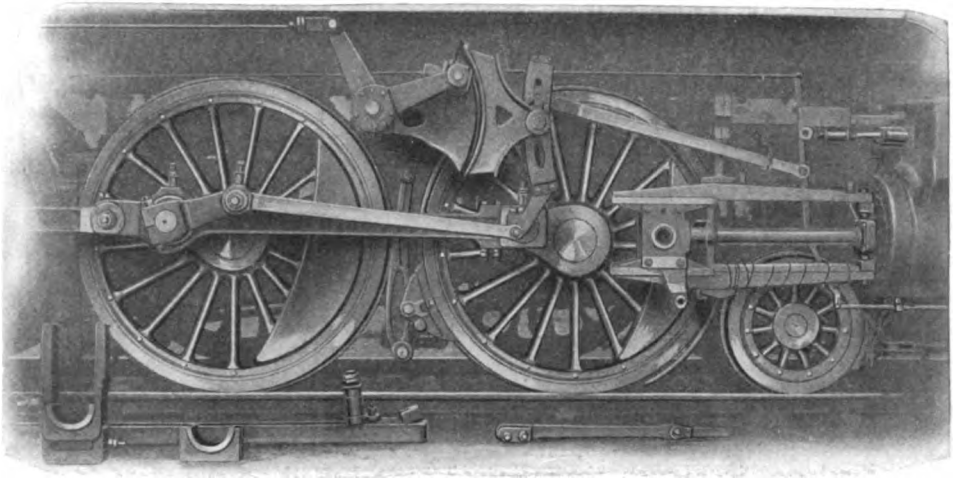

FIG. 58.—Breakdown, Walschaerts gear.

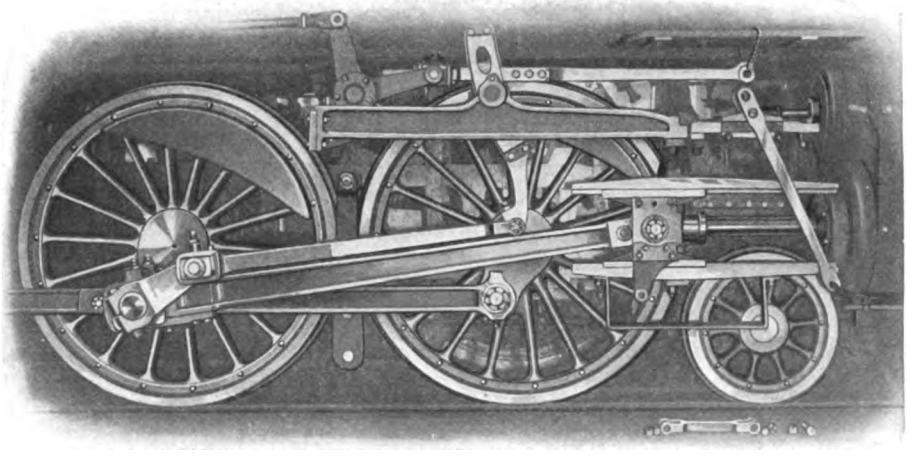

FIG. 59.—Breakdown, Walschaerts gear.

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the front end of the radius rod from the valve stem crosshead guide, using for this purpose a wire or chain (the fire door chain if no other is at hand). Secure the valve to cover the ports, and if necessary remove the main rod and block the crosshead at the back end of the guide.

NOTE.—If the engine has cylinder relief valves and the main rod and piston on the disabled side are in condition to run, the main rod may be left up when the valve is secured to cover the ports. In that event remove the relief valves from the cylinder heads to relieve compression and also permit of lubricating the cylinder.

If the lap and lead lever, lap and lead lever connector, or crosshead arm break; with inside admission valves and relief valves in the cylinder heads an engine can be blocked, as shown in Fig. 59. Disconnect the radius rod from the lap and lead lever and suspend it clear of the latter, as shown. Secure the valve to cover the ports. Tie the lower end of the lap and lead lever ahead by means of a rope secured to the cylinder cocks. Take out the relief valves. The engine can then be run with one side.

With outside admission valves under the same conditions as illustrated in Fig. 59, the main rod could be left up and the engine disconnected in the same way, except that the lap and lead lever would have to be taken down in order to clear the radius rod.

BAKER GEAR.

With the Baker Gear there are two ways for blocking the gear and valve in case of breakdown. The valve stem crosshead is provided with a set-screw so that the valve can be blocked central over the ports by clamping the valve stem crosshead to its guide. This is done in case the breakage of the gear or engine disables one side.

The other way of blocking is by bolting the lower arm of the bell-crank fast to the side of the frame. After the valves have been set, the reverse lever is put in midgear and a hole drilled through frame and bell-crank arm. Any bolt that will go through the hole can be used. (See Figs. 52 and 53, Baker Gear, in Part VII.)

In the latest designs of Baker Gear two holes are drilled into the gear frame and a clamp is provided to encircle the bell-crank and hold it stationary. This provision makes it practicable to get the lap and lead movement when the following parts fail: Eccentric crank, eccentric rod, gear connecting rod, radius bar, reverse yoke, short reach rod and horizontal arm of bell-crank. In case any of these parts break bolt the bell-crank arm fast and remove the eccentric rod. With the gear bolted in this manner the valve will get the lap and lead movement and a port opening equal to the lead for all cut-offs, obtaining the same advantages as outlined in second paragraph, Breakdowns, Walschaerts Gear.

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Broken Eccentric Crank or Eccentric Rod.—Remove the broken parts. If it is the eccentric crank that fails, it is necessary to remove the eccentric rod. Secure the arm of the bell-crank in a perpendicular position and allow the crosshead to give the lap and lead movement to the valve as outlined in the previous paragraph.

Broken Gear Connecting Rod, Radius Bar, Gear Reach Rod, or Reverse Yoke.—Remove the eccentric rod and also broken parts. Secure the arm of the bell-crank and proceed as outlined in the previous paragraph.

Broken Bell Crank.—If the horizontal arm of the bell-crank fails, follow instructions of previous paragraphs. If it should be one of the vertical arms, however, disconnect the valve rod, combination lever and union link, clamp the valve so as to cover the ports, and proceed with locomotive working on one side.

Broken Union Link or Crosshead Arm.—Remove the broken parts, disconnect the valve rod and clamp the valve covering the ports unless the construction of the locomotive is such that the combination lever can be secured in practically a vertical position. If the combination lever can be so secured remove the broken parts, secure the combination lever in a vertical position, and the valve will receive a movement equal to the throw of the eccentric crank, which will give a reduced though effective port opening.

Broken Combination Lever.—If the break will not permit of the broken combination lever being secured as outlined in previous paragraph, remove the broken parts, disconnect the valve rod, clamp the valve to cover the ports and proceed with the locomotive working on one side.

Broken Valve Rod.—Remove the broken parts, clamp the valve so as to cover the ports and proceed with the locomotive working on one side.

RUNNING GEAR AND MACHINERY.

Broken Main Pin.—With a broken main crank pin it will be necessary to remove all the side rods on each side and the main rod on the disordered side unless the main rod runs through the guide yoke, then it can be carried resting on the guide yoke or bottom guide with the piston moved ahead and the crosshead blocked.

Broken Piston Rod.—The break in a piston rod usually occurs where the rod is keyed to the crosshead. When a piston rod breaks the piston knocks out front head of cylinder, so all that is necessary to do is to take off the valve rod, clamp valve stem with valve in mid-position and proceed with one side.

Broken Strap on Main Rod.—A broken main rod strap, either front or back end, usually results in front head of cylinder being knocked out. Proceed the same as with a broken piston rod.

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Broken Guide.—With a guide bar broken, the safest plan to prevent further damage is to remove main rod, after disconnecting the valve rod and clamping the valve in mid-position, and blocking the crosshead.

Broken Crosshead.—Disconnect valve rod, clamp valve stem with valve in mid-position, remove main rod and block what remains of the crosshead so as to hold piston in one position.

Broken Cylinder Head.—Clamp the valve stem with the valve in mid-position, disconnect the valve rod and if the front head is broken, the main rod can remain up. If the back head is broken so that guide bars are damaged it will be necessary to take the main rod down and block crosshead to hold the piston in one position.

NOTE.—In cases where disorder necessitates disconnecting valve rod and covering ports with valve, the main rod, provided its connections are in good order, can be allowed to remain up if it is practicable to oil the cylinder. On locomotives having indicator plugs or direct oil pipe to cylinder, the cylinder can be oiled through the indicator plug holes, or by the lubricator through the direct oil pipe. When the cylinders have no indicator plugs or direct oil pipe it is practicable to oil the cylinder by placing the valve so that one steam port is open slightly, allowing steam to flow to the cylinder, carrying with it oil fed from the lubricator. With this latter method the cylinder cock should be removed to permit circulation.

Broken Side Rod or Back Pin.—4–4–0 type. Remove side rods on both sides and proceed.

Broken Side Rod or Front Pin.—4–4–2 type. Proceed in the same manner as you would with a broken side rod or back pin on a 4–4–0 type of locomotive.

Broken Front Section of Side Rod.—All types with knuckle joint pin between first and second pair of drivers. Remove broken section and corresponding section on opposite side, and proceed if no further damage has been done.

Broken Back Section of Side Rod.—All types with knuckle joint pin between the last two pair of drivers. Remove broken section and corresponding section on opposite side and proceed.

Broken Back Section of Side Rod.—2–6–0, 2–6–2, 4–6–2 types. Remove the back section on each side and proceed.

Broken Front Section of Side Rod.—2–6–0, 2–6–2, 4–6–2 types. Remove all side rods on the locomotive.

Broken Intermediate or Middle Section of Side Rod.—2–8–0 and 2–8–2 types, or section ahead of main pin on types with five pair of drivers. Remove all side rods on the locomotive, unless permissible to remove side rods and main rod on one side, allowing all rods to remain connected on opposite side, as outlined in the beginning of this Part.

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Broken Tire on Front Driver.—4–4–0 type. Run the wheel with the broken tire on a block until it is raised 4 or 5 inches above the rail and place an iron block or large nuts between the top of the frame and the spring saddle. Remove oil cellar or grease box and place wooden blocks between journal and pedestal brace to carry weight of the box and wheel. Space around axle should be filled with waste well saturated with oil to lubricate the journal as it turns on the wooden block.

Broken Back Tire.—4–4–0 type. Proceed the same as for a front tire in raising the wheel from the rail, remove the oil or grease cellar and block between the journal and pedestal brace. Place an iron block or large nut between the top of the frame and spring saddle. If the break occurs on an engine having underhung springs, the back end of the equalizer must be chained up or else the front end blocked down.

Broken Tire on Front Driver.—4–4–2 type. Proceed in the same manner as in the event of a back tire breaking on a 4–4–0 type.

Broken Tire on Main Driver.—4–4–2 type. Proceed in same manner as for a broken main tire on a 4–4–0 type.

Broken Tire on Front Driver.—All types with a two-wheel or pony truck. Run wheel with broken tire up on a block so that its height above rail will equal thickness of tire, remove oil or grease cellar and block between journal and pedestal brace. Block between frame and spring saddle to relieve front driving box of weight, and run carefully around curves if second pair of wheels are without flanges.

Broken Tire on Second Driver.—All types having more than three pair of drivers. Run that wheel up on a block about the thickness of the tire and block between spring saddle and frame and between journal and pedestal cap. Blocking in this manner gives the advantage of using all the springs.

Broken Tire on Main Driver.—All types having three or more pair of drivers. Run main driver up on a block the thickness of tire and block as in previous paragraph.

Broken Tire on Back Driver.—2–6–0, 2–8–0 types. Run wheel up on a block the thickness of tire, remove oil cellar and block between journal and pedestal brace. Take weight off this box by placing blocks between front end of back spring and bottom rail of frame and between back end of back equalizer and bottom rail of frame.

Broken Pony Truck Center Pin or Long Equalizer.—Raise front of locomotive a little above its normal position to take tension off of front driving springs. Jack up front end of equalizer and place a piece of hard wood or a truck brass on top of truck axle and allow the end of the equalizer to rest on it. Keep well oiled where the brass rides the axle. Should the equalizer break between the fulcrum and the end so that a truck brass cannot be used on the axle, jack up equalizer and chain it securely to a short piece of rail or track tie

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placed across frame in front of cylinder saddle. Run carefully with a locomotive blocked in this manner.

Broken Front Axle.—4–4–0 type. When a front axle breaks outside the driving box, disconnect the main rod on that side, remove the side rod, disconnect the valve rod and clamp the valve stem with valve in mid-position. Run carefully without train.

Broken Back Axle.—4–4–0 type. Remove both side rods, block up the back pair of wheels the same as for broken tire except removing the oil cellars. Proceed with as much train as the locomotive will haul with front pair of drivers.

Broken Front Axle.—4–4–2 type. Remove both side rods, jack up end of axle until it is in its normal position, remove cellar and block between the journal and pedestal brace, also block between top of frame and spring saddle so as to take the weight off of box and place it on the frame.

Broken Main Axle.—4–4–2 type. Remove both side rods and the main rod on the disabled side, drop the main wheel on the disordered side out of the way and block the same as for the front axle. Disconnect the valve stem and cover the ports on the disordered side.

Broken Front Axle.—All types with three or more pair of drivers. When the front driving axle breaks outside the box it is necessary to remove the front sections of both side rods. Remove the driving wheel, jack up the broken end of axle until it is in its normal position blocking between the journal and the pedestal brace, and block between the top of the frame and the spring saddle in order to relieve the box of weight. If the following pair or pairs of drivers have plain tires, great care must be exercised in moving around curves in order that the wheels with plain tires may not drop off of the rails.

Broken Second Axle.—All types with four or more pair of drivers. If the axle breaks outside the box it is necessary to remove all side rods. Jack up broken end and block up between it and pedestal brace same as for broken axle 4–4–2 type and block between top of driving box and spring saddle to relieve box of its load.

Broken Main Axle.—All types with four or more pair of drivers. If no other damage should be done remove all side rods and main rod on disordered side. Block same as for second axle. If main wheels have blind tires and no collars on axles it will be necessary to swing main wheel to clear the rail on opposite side. In this case both main drivers will be out of service and the engine must be towed.

Broken Main Driving Spring or Hanger.—4–4–0 type. Run the main driver of the disordered side up on a block so as to relieve the back spring, pry up the front end of the equalizer into a level position and block it there, run main driver off of the block, and the back driver up on one and block on top of the main box under the frame. After running the engine off of the block, slacken down the main

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wedge to prevent box sticking if it should run hot and keep wedge and shoes well oiled.

Broken Back Driving Spring or Hanger.—4-4-0 type. With an engine having overhung spring rigging, run the back wheel up on a block to take strain off main spring and pry the back end of equalizer level and block it, run back wheel off block and main wheel up on one and place a block on top of the back box under the frame levelling the engine, slacken the back wedge and keep driving box well oiled.

Broken Equalizer.—4-4-0 type. Run back driver up on a block so that a piece of iron or large nuts can be placed on top of the main box under frame bar. Then run the back driver off the block and main driver up on one, and block between back driving box and frame. The broken equalizer and loose spring rigging should be removed to prevent further damage and boxes oiled freely, as they are liable to run hot.

Broken Main Driving Spring.—4-4-2 type. On locomotives having overhung spring rigging, run main driver up on a block, to relieve the springs, pry up back end of front equalizer to its normal position and place a block between back end of equalizer and bottom rail of frame. Pry down the back end of back equalizer and block between top rail of frame and back equalizer. Run main driver off of block and front driver up on one, block between top of main box and top rail of frame. Remove broken or loose parts to prevent further damage. This method permits of using front and trailer springs.

Broken Front Spring or Hanger.—4-4-2 type. Run the front driver up on a block to relieve spring rigging, pry down on back end of front equalizer until it is in normal position, and block between the front end of this equalizer and the bottom rail of the frame. Run the front driver off of block and the main driver up on one and block between the top of the front box and frame, thus permitting the front driver to carry its share of the load.

NOTE (Broken Tires).—In all cases of broken tires the objective point is to raise the wheel center a height equal to the thickness of the tire, thus levelling the axle, blocking in such manner as to relieve the driving box over journal of disordered wheel, redistributing the weight over the other boxes. When the tire of main wheel is broken it will be necessary to put engine out of commission on disordered side, removing main and side rods if damaged at time of tire breakage. When the tires of back wheels are broken and there are no flanges on the tires of the pair ahead it will be necessary to hold back end of locomotive over toward the side having good tire, which may be done by fastening a heavy chain from the tail piece of frame on disordered side to front end of opposite side of tender. This method will guide back end of locomotive and keep it on the rail, though it must be run carefully on curves and over frogs and switches. Tire breakage hap-

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pens less frequently than tires becoming loose and working off, for which the same instructions can be followed as for tire breakage, or the loose tire replaced by tire heating apparatus. Tire heating apparatus is carried in most wrecking outfits.

American Locomotive Company's Articulated Compound Locomotive.—In case of any disorder in which one or more of the cylinders can be made inoperative and the locomotive run in with the remaining cylinders active, throw the emergency operating valve (N), Fig. 10, in the cab into the simple position and proceed as with a simple locomotive. This is the rule to follow and the only one to be remembered, and covers all cases of accidents which do not entirely disable the locomotive. To test for blows in the valves or pistons, throw the emergency operating valve in the cab to the simple position, namely, with the handle pointing *backward,* and test the same as a simple locomotive.

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PART X

PARTS AND APPLIANCES

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PARTS AND APPLIANCES.

THIS part contains descriptions and illustrations of locomotive parts, appliances and fixtures, and also notes on some subjects not mentioned in the previous text.

Arch Pipe.—A large water tube extending through the firebox at an angle from the back tube or inside throat sheet to the door sheet above the fire door for the purpose of supporting the brick arch. Usually three are used for the support of the brick arch. In Fig. 60 the arch pipe can be plainly seen.

Badge Plate (for boiler pressure).—A metal plate fastened to the back head of boiler or some other prominent place in the cab with

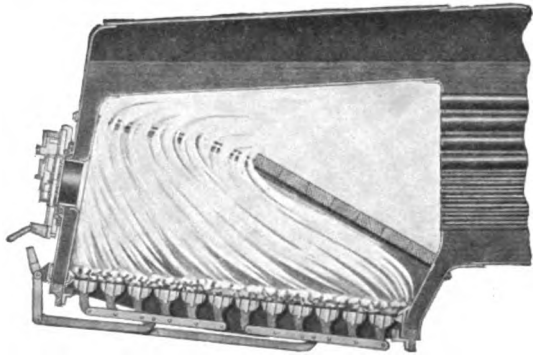

FIG. 60.—Security sectional arch.

figures indicating the allowed boiler pressure. Same, plate attached to outside of smoke box or side of steam chest showing builder's name and construction number, date built, oftentimes class, and other information relating to the locomotive. Same, plate attached to bulkhead of tenders with figures indicating fuel and water capacity.

Blow-off Cock.—A plug valve of large opening, screwed into the outside of lower part of the firebox, used for emptying the boiler.

Brick Arch.—A flat or arched construction of fire brick, supported by studs or water tubes placed across the firebox, extending from the tube sheet back toward the crown sheet at an angle of about 45°. Its purpose is to mix the firebox gases, promote combustion, and thereby prevent the formation of black smoke. See Fig. 60.

Expansion Pad or Expansion Brace.—A plate or casting attached to the frames to make a suitable connection with the firebox, which allows free movement of the boiler longitudinally owing to expansion and contraction, though permitting very little movement in an upward or lateral direction. See No. 82, Fig. 79.

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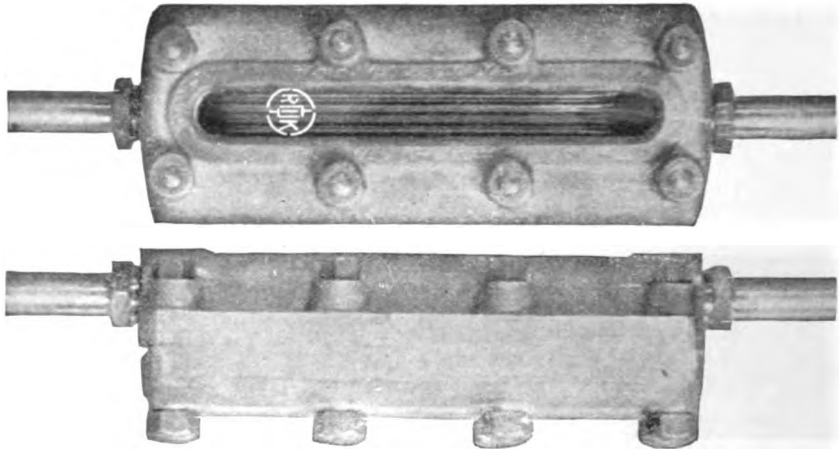

FIG. 61.—Klinger reflex water gauge.

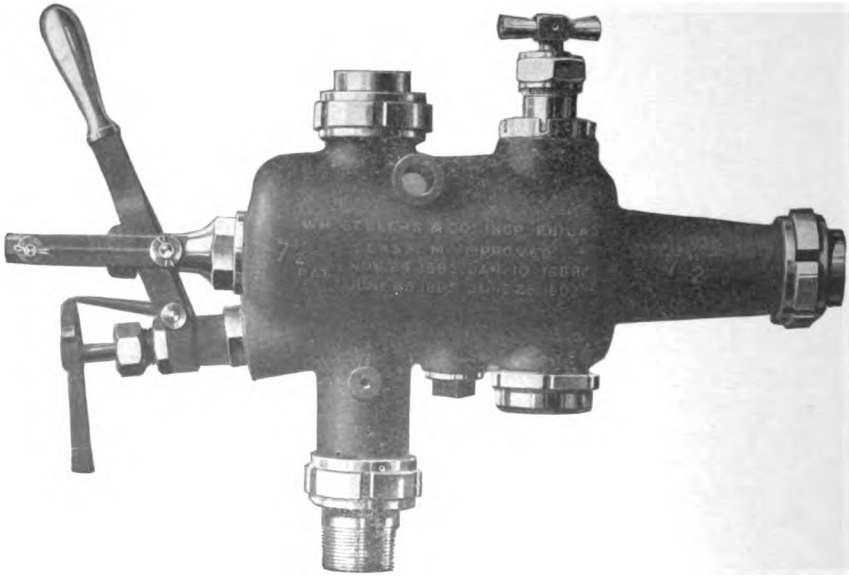

FIG. 62.—Sellers self-acting injector of 1887—Class M improved.

Frame Splice.—A joint or connection between two portions of a locomotive frame. The connection is secured by tapered bolts carefully and tightly fitted in tapered bolt holes, and also by keys driven into key ways or slots.

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Glass Water Gauge.—Fig. 61 shows the Klinger reflex glass water gauge.

Injectors.—The following illustrates, describes, and names the important parts of the Sellers, Nathan, and Ohio injectors.

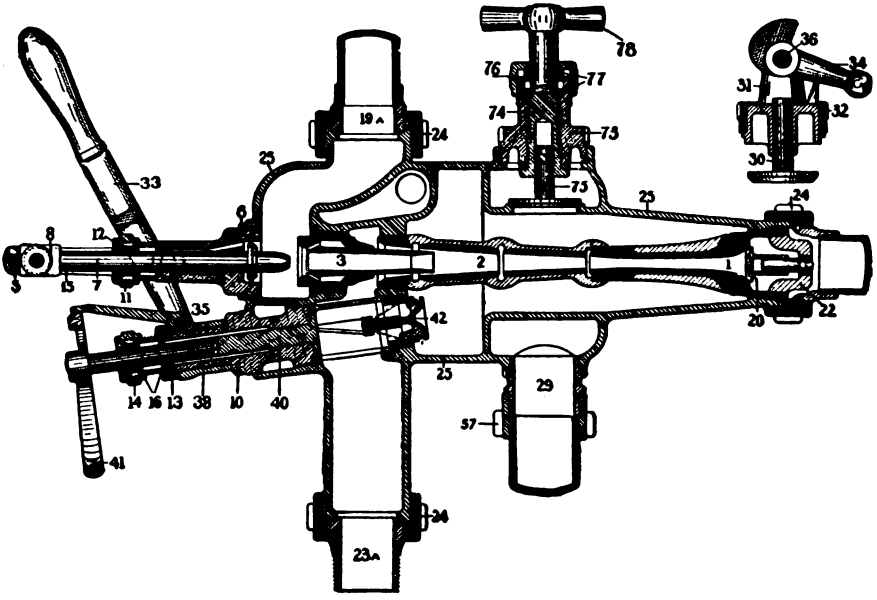

FIG. 63.—Sellers self-acting injector of 1887—Class M improved (sectional view).

1	Delivery tube.	16	Packing ring.	33	Starting lever.
2	Combining tube.	19	Plain rings for copper pipe.	35	Pin, Nos. 9 and 33.
3	Steam nozzles.	19a	Reducing rings for copper pipe.	38	Collar and index.
5	Spindle nut.	20	Check valve.	39	Funnel.
6	Steam stuffing box.	22	Guide for No. 20.	40	Plug water valve.
7	Spindle.	23	Plain unions for iron pipes.	41	Regulating handle.
8	Crosshead.	23a	Reducing unions for iron pipes.	42	Inlet valve.
10	Water stuffing box.	24	Coupling nut.	73	Guide for overflow valve.
11	Follower.	25	Injector body.	74	Heater stem.
12	Packing ring.	27	Wrench.	75	Overflow valve.
13	Lock nut.	29	Waste pipe.	76	Follower on No. 73.
14	Follower for No. 10.			77	Packing ring in No. 73
15	Links.			78	Heater lever.

Figs. 62 and 63 show Sellers Self-acting Injector of 1887, Class M Improved, followed by a list of parts.

Method of Operating: To start, pull out lever slowly until injector primes and then pull it out all the way. Regulate for quantity of water with the regulating valve. To stop, push in lever till steam valve seats. To use as a heater, follow method outlined in Part V relating to converting injector into heater.

Fig. 64 shows Sellers Improved Self-acting Injector, Class P, which are placed on back heads of boilers, followed by a list of parts.

Method of Operating: Same as Class M.

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Fig. 65 shows Sellers Self-acting Injector, Class K, N–L, Non-lifting, followed by a list of parts.

Method of Operating: Open overflow, water and steam valves. Regulate for quantity of water with the regulating valve. When the

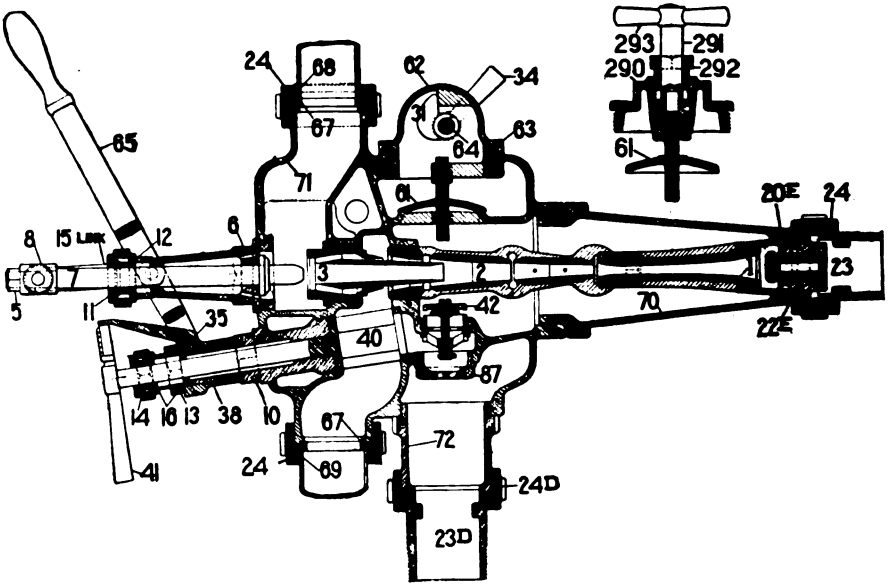

FIG. 64.—Improved self-acting injector—Class P.

1 Delivery tube.
2 Combining tube.
3 Steam nozzles.
5 Spindle nut.
6 Steam stuffing box.
7 Spindle.
8 Crosshead.
10 Water stuffing box.
11 Follower.
12 Packing ring.
13 Lock nut.
14 Follower for No. 10.
15 Links.
16 Packing rings.
19 Plain rings for copper pipe.
19a Reducing rings for copper pipe.
20 Check valve.
22 Guide for No. 20.
23 Union for delivery.
23d Union for iron waste pipe.
24 Coupling nuts for steam, water and delivery.
24d Coupling nut for waste pipe.
27 Wrench.
31 Waste valve cam.
34 Cam lever.
35 Pin, Nos. 38 and 65.
37 Washer on No. 64.
38 Collar and index.
40 Plug water valve.
41 Regulating handle.
42 Inlet valve.
61 Waste valve.
62 Hood over No. 61.
63 Jam nut on No. 62.
64 Cam shaft.
65 Starting lever, right-hand injector.
66 Starting lever, left-hand injector.
67 Seat ring, P. R. R. Std.
68 Steam and delivery pipe rings.
69 Suction pipe ring.
70 Lower cylinder.
71 Upper cylinder.
72 Waste pipe.

water supply has a temperature between 106° and 147° close the overflow valves. To use as heater, close the overflow valve.

The Class K non-lifting injector is self-acting, embodying all the features of the lifting form, excepting that the water supply must flow to it under a head, necessitating it being placed below the bottom of the tender tank, usually on the back end of the locomotive frame under the cab. This injector is provided with a balanced inlet valve that gives additional flow of water to the tubes when the injector is

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operating, surrounding the tubes with comparatively cold water, reducing the tendency for scale forming on their interior, which enables

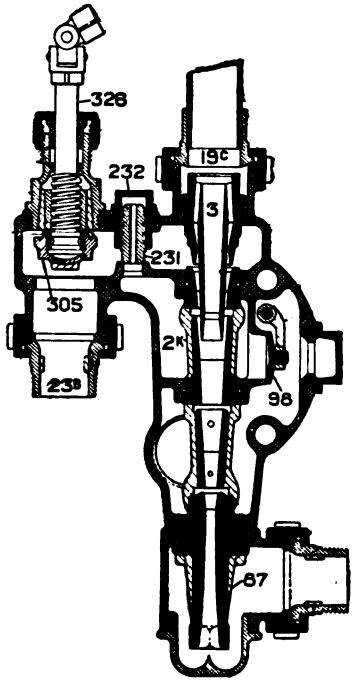

FIG. 65.—Sellers self-acting injector—Class K, N-L, non-lifting.

2k Combining tube.	23b Water union for iron pipe.	231 Inlet valve.
3 Steam nozzle.	87 Delivery tube.	232 Cap over 231
19c Steam ring for copper pipe.	98 Hot water valve.	305 Lazy cock valve.

the injector to maintain its rated capacity. It is also restarting—*i.e.*, if the water supply is temporarily interrupted the injector will restart automatically as soon as the supply is restored. It is designed for feeding hot water, and the temperature of supply water at which it will operate ranges between the values given in the following table:

	Pressure of Steam				
	60	120	150	180	200
Overflowing temperature, or maximum temperature at which injector will restart, degrees Fahrenheit	135	122	120	112	106
Breaking temperature, waste valve closed, degrees Fahrenheit	145	150	151	149	147

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Fig. 66 shows Self-acting Injector Improved, Class N–L of 1908, followed by list of parts.

This injector is similar to the Class K, N–L, and is provided with an automatic lazy cock that allows no waste of water from the tank

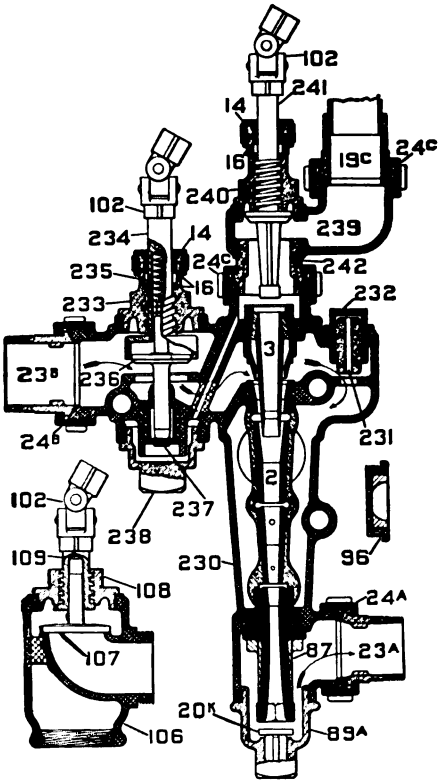

FIG. 66.—Self-acting injector improved—Class N–L of 1908 (with attached automatic lazy cock).

2 Combining tube.
3 Steam nozzle.
14 Follower.
16 Packing ring.
19a Delivery ring for copper pipe.
19c Steam ring for copper pipe.
20k Line check valve.
23a Delivery union for iron pipe.
23b Water union for iron pipe.
23c Steam union for iron pipe.
24a Delivery coupling nut.
24b Water coupling nut.
24c Steam coupling nut.
87 Delivery tube.
89a Bottom cap.
96 Side cap in 230.
102 Universal joint.
106 Waste pipe.
107 Waste valve.
108 Cap over 107.
109 Screw waste valve stem.
230 Injector body.
231 Inlet valve.
232 Cap over 231.
233 Stuffing box for lazy cock.
234 Lazy cock valve.
235 Spring in 234.
236 Automatic check valve.
237 Piston.
238 Cap under 237.

when the steam valve is closed. When the steam valve is opened, steam is admitted against the small piston under the lazy cock, raises the check valve, allowing water to flow into the injector in the direc-

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tion shown by the arrows in the sectional view, Fig. 66. The screw lazy cock above the check valve is for the purpose of regulating feed and must not be closed when the injector is not in operation.

Method of Operating: To Start Feed. Open waste valve and lazy cock; then open starting valve slowly; adjust lazy cock to suit feed.

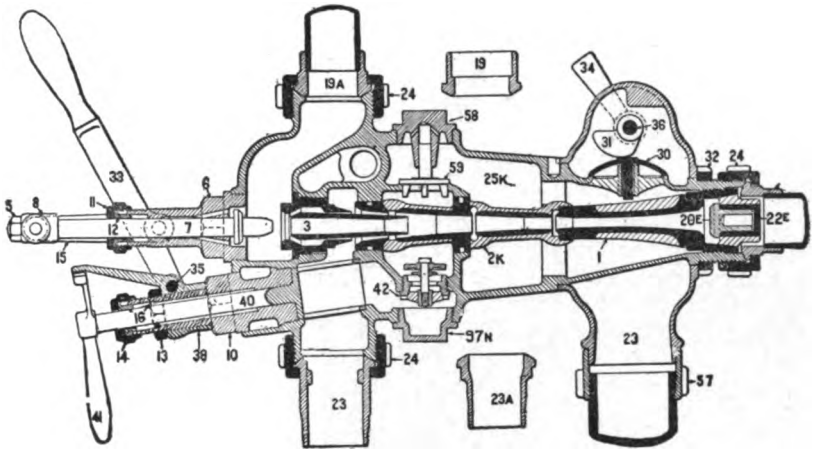

FIG. 67.—Improved self-acting injector—Class K (for hot water).

1 Delivery tube.
2k Combining tube.
3 Steam nozzles.
5 Spindle nut.
6 Steam stuffing box.
7 Spindle
8 Crosshead.
10 Water stuffing box.
11 Follower.
12 Packing ring.
13 Lock nut.
14 Follower on No. 10.
15 Links.
16 Packing rings.
19 Plain rings for copper pipe.
19a Reducing rings for copper pipe.
20 Check valve.
22 Guide for No. 20.
23 Plain unions for iron pipes.
23a Reducing unions for iron pipes.
24 Coupling nuts.
25k Injector body.
27 Wrench.
29 Waste pipe.
30 Waste valve.
31 Waste valve cam.
32 Jam nut for No. 29.
33 Starting lever.
34 Cam lever.
35 Pin, Nos. 38 and 33.
36 Cam shaft.
37 Washer on No. 36.
38 Collar and index.
40 Plug water valve.
41 Regulating handle.
42 Inlet valve.
57 Iron overflow.
57a Copper overflow.
58 Cap over hot water valve.
59 Hot water valve.

To Stop Feed: Close steam valve; let lazy cock remain in open position.

To Use as Heater: Close waste valve and open steam valve and lazy cock.

Fig. 67 shows Improved Self-acting Injector, Class K, followed by list of parts.

It is a lifting injector designed for feeding hot water, and the temperature of supply water at which it will operate ranges between temperatures given in following table:

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	Pressure of Steam				
	60	120	150	180	200
Overflowing temperature or maximum temperature at which injector will restart, degrees Fahrenheit	135	122	120	110	104
Limiting temperature, waste valve closed, degrees	145	150	150	149	147

Method of Operating: To start, pull out the lever. To stop, push in the lever. Regulate for quantity with the water-regulating handle. In starting on high lifts and in lifting hot water it is best to pull out the lever slowly. This injector should always be set horizontally. It may be placed on a locomotive wherever it is most convenient to the engineer. (The capacities of all injectors are reduced by increasing the temperature of the water supply.) The figures in table above must be reduced 20 per cent. when the temperature of the supply is 120°, and 30 per cent. at 140°.

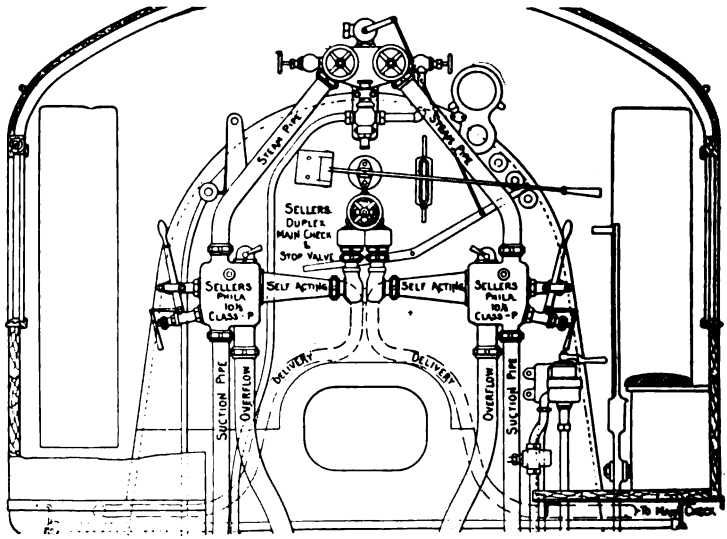

FIG. 68.—Injectors attached to back head.

For Hot Water: When the temperature of the water supply exceeds the overflowing temperature, start as above, then turn the cam lever toward steam branch. At all other times the cam lever No. 34 must point toward the delivery end, so that injector may restart.

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Fig. 68 shows method of attaching lifting injectors to back head of locomotive boiler. With this method of attaching injectors both boiler check valves are contained in one casting, the check valve chambers communicating with a single delivery pipe that passes through the interior of the boiler and discharges the feed water in the front of the boiler.

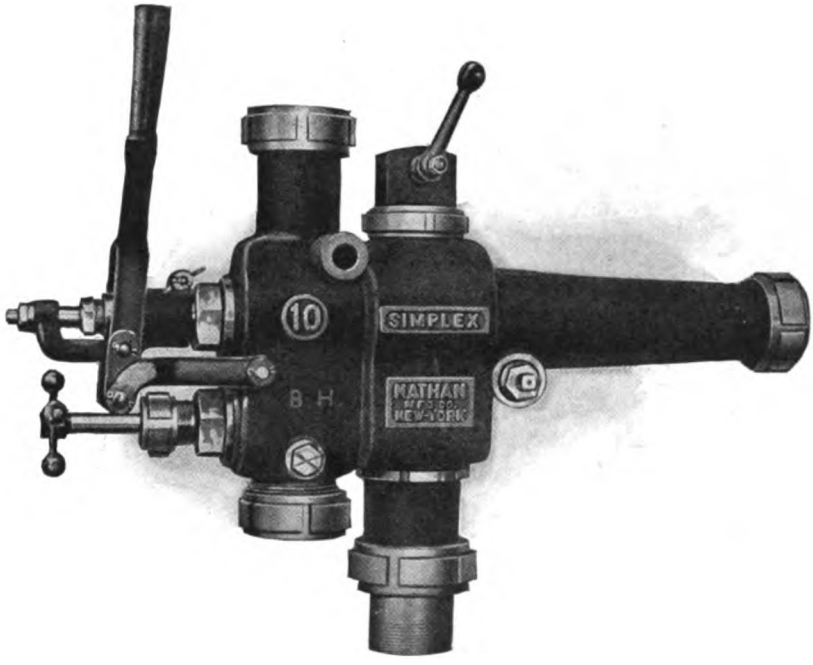

FIG. 69.—Nathan injector. Simplex type "B. H."

Figs. 69 and 70 show the Nathan Manufacturing Company's Simplex Type B. H. Injector, followed by a list of parts.

Method of Operating: To start, pull out the lever. Regulate the quantity by means of the water valve. On high lifts or lifting hot water, pull the lever out slowly when starting. To stop, push in lever. To use as heater, close heater cock and draw out lever.

NOTE.—If water inlet valve (part 19) should leak and prevent the prompt lifting of feed water, turn key 35, so that letter "S" (not shown in cut) on square spindle end will be up. This closes passage "P," and permits the continued use of injector until valve 19 can be repaired.

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Figs. 71 and 72 show Type "Nathan" Non-lifting Injector, followed by list of parts.

Method of Operating: To start, open steam valve (starting valve). slowly at first until overflow runs dry. Do not increase the steam

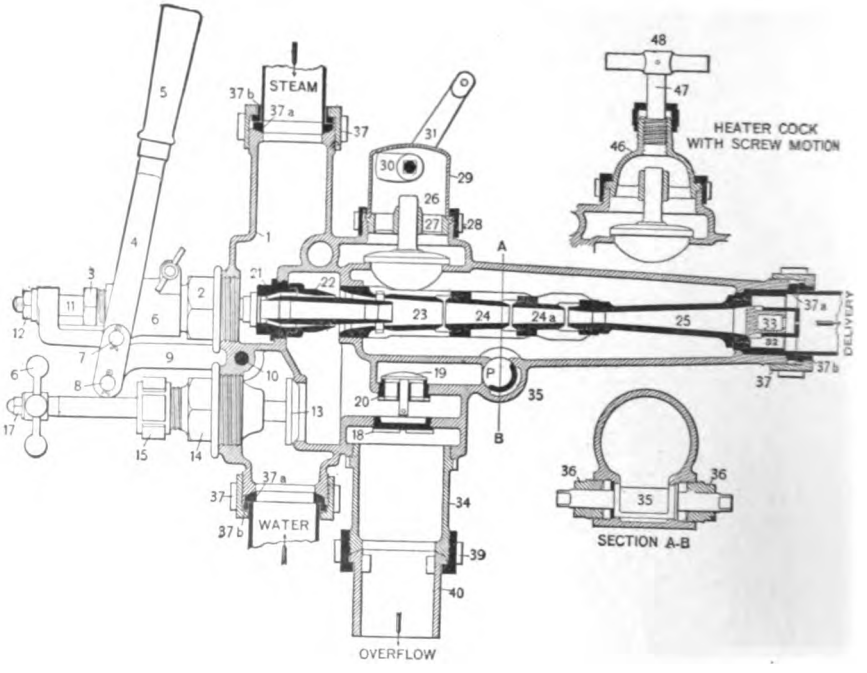

FIG. 70.—Nathan injector. Simplex type "B. H."

1	Body.	16	Water valve handle.	30	Cam.
2	Steam bonnet.	17	Water valve top nut.	31	Cam lever.
3	Steam packing nut.	18	Inlet valve cap.	32	Nozzle holder.
4	Lever.	19	Inlet valve.	33	Line check valve.
5	Lever handle.	20	Inlet valve seat.	34	Overflow nozzle.
6	Guide for steam spindle.	21	Steam nozzle.	35	Emergency valve.
7	Guide pin.	22	Lifting steam nozzle.	36	Packing nut for emergency valve.
8	Lever pin.	23	Intermediate nozzle.	37	Coupling nut. } Steam, water
9	Fulcrum bar.	24	Combining nozzle.	37a	Ball joint. } or delivery
10	Fulcrum pin.	24a	Combining nozzle.	37b	Brazing ring. } (specify).
11	Steam spindle.	25	Delivery nozzle.	39	Overflow coupling nut.
12	Lock nut.	26	Heater cock check.	40	Overflow tailpiece.
13	Water valve.	27	Guide for heater cock check.	46	Guide for heater cock. } For heater
14	Water valve bonnet.	28	Nut for cam casing.	47	Heater cock spindle. } cock with
15	Water valve nut.	29	Cam casing.	48	Heater cock handle. } screw motion.

supply after overflow has ceased. Regulate for quantity by water valve, or to reduce capacity of injector reduce steam and water supply to the desired degree. To stop, shut steam valve.

To Use as Heater: Close heater cock H and open steam valve. At all other times cock H must be wide open.

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NOTE.—The water valve of the injector when once regulated to the requirements of the service need not be changed. Leaving it open keeps the injector charged with water and prevents corrosion of nozzles.

Figs. 73 and 74 show Simplex, Type H. W. Non-lifting Injector, followed by list of parts.

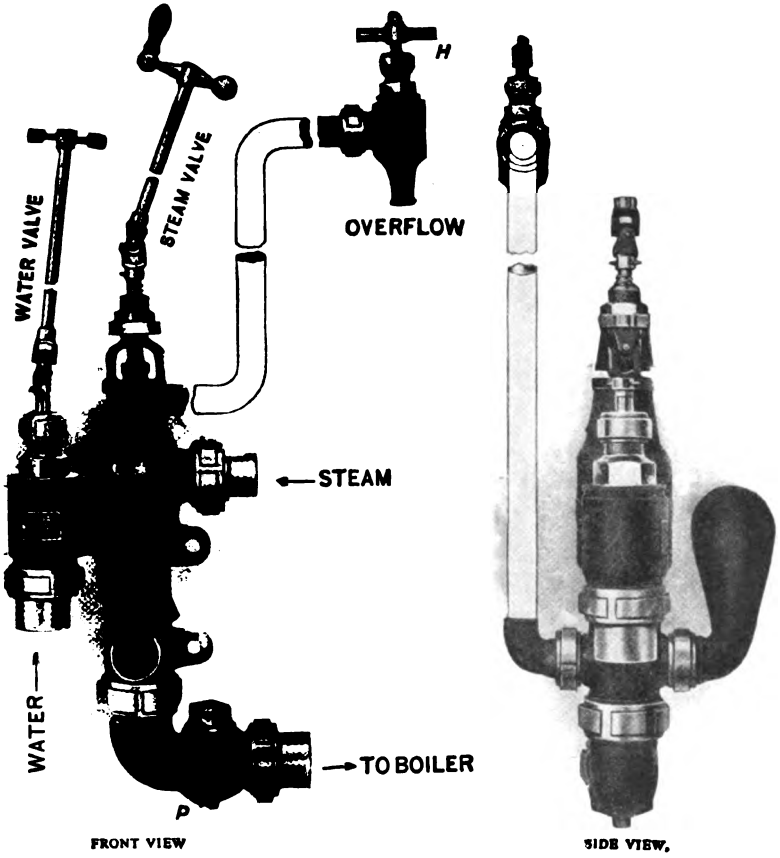

FIG. 71.—Nathan injector, type "Nathan."

This injector will operate with hot supply water, which may have a temperature of 125° at 200 pounds steam pressure, and 145° at 125 pounds steam pressure.

Method of Operating: To start, open water valve (lazy cock) first, then the steam valve. Regulate for quantity by water valve. With warm feed water, close the overflow after the injector has

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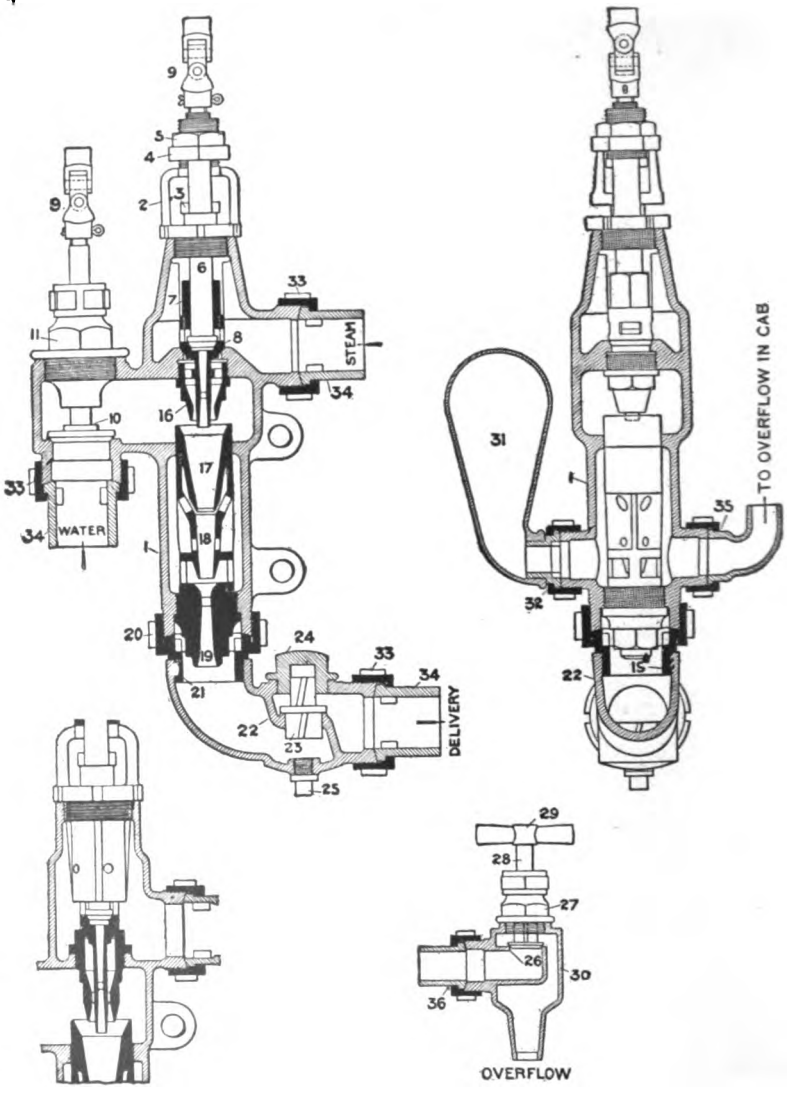

FIG. 72.—Nathan injector, type "Nathan."

1 Body.
2 Yoke.
3 Yoke gland.
4 Yoke packing nut.
5 Yoke lock nut.
6 Steam valve spindle.
7 Steam valve lock nut.
8 Steam valve and priming nozzle.
9 Universal joint.
10 Water valve.
11 Water valve bonnet and nut.
16 Steam nozzle.
17 Intermediate nozzle.
18 Condensing nozzle.
19 Delivery nozzle.
20 Line-check nut.
21 Line-check nipple.
22 Line-check.
23 Line-check valve.
24 Line-check cap.
25 Drain plug.
26 Heater cock check.
27 Heater cock bonnet and nut.
28 Heater cock spindle.
29 Heater cock handle.
30 Overflow body.
31 Air chamber.
32 Air chamber nut and nipple
33 Coupling nut—steam, water or delivery (specify).
34 Tailpiece—steam, water or delivery (specify).
35 Lower overflow nut and tailpiece.
36 Upper overflow nut and tailpiece.

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started, and in stopping close steam and water valves and open overflow valve. To stop, close steam valve first, then water valve.

To Use as Heater: Close overflow valve and open steam valve slightly. At all other times overflow valve must be wide open.

Fig. 75 shows the Ohio Injector Co.'s "Ohio" Lifting Injector.

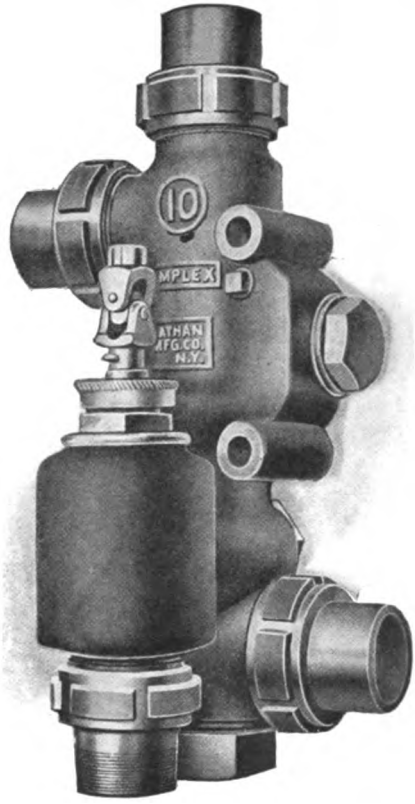

FIG. 73.—Nathan injector, type H.W., non-lifting.

To Operate: To start, pull lever back until the resistance of primer is felt. Soon as water appears at overflow, pull lever back as far as it will go. Regulate for quantity of water needed by water valve.

To Use as a Heater: Close overflow valve, pull lever back until resistance of primer is felt and let stand at this point. Overflow valve must not be closed except when injector is to be used as a heater.

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Fig. 76 shows Chicago Standard "R" Non-lifting Injector, followed by a list of parts. Method of Operating: To start, first turn on steam with main steam valve at fountain or boiler. Turn overflow valve full open. Open water valve full. Pull lever steam throttle

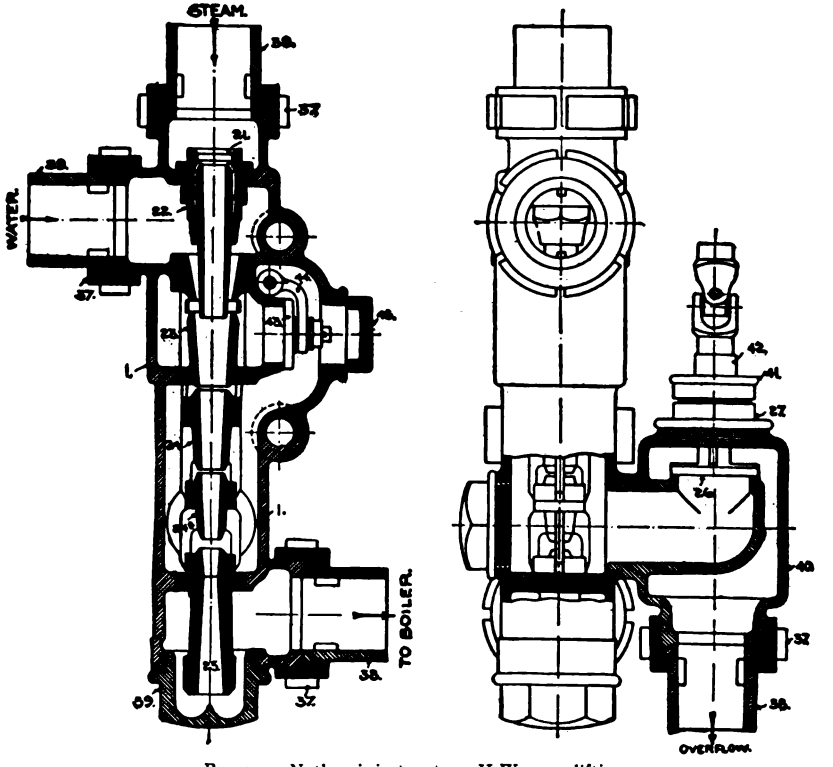

FIG. 74.—Nathan injector, type H.W., non-lifting.

1	Body.	26	Heater cock check.	40	Overflow casing.
21	Steam nozzle.	27	Guide for heater cock check.	41	Overflow cap.
22	Jet nozzle.			42	Overflow spindle.
23	Intermediate nozzle.	37	Coupling nut (steam, water, delivery or overflow (specify).	43	Hinge check.
24	Combining nozzle.	38	Tailpiece	44	Hinge.
24a	Combining nozzle.			45	Hinge cap.
25	Delivery nozzle.	39	Nozzle cap		

valve open to start injector. The water supply should then be regulated with water valve. When injector is shut off close overflow valve.

To Use as a Heater: Close overflow valve; pull lever steam throttle valve open; then regulate steam with main steam valve or water valve.

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Knuckle Joint.—A joint in side rods to give them flexibility so as to adapt themselves to unevenness of track.

Link.—A slotted lever, slightly curved, part of valve gear. It is the device used for shortening the valve travel and reversing the engine. A link has a curved slot in which the link block works, and the slot is curved for the purpose of making the valve move an equal distance on both sides of its center position. See No. 48, Fig. 77.

Locomotive.—Fig. 77 shows a line drawing of a 4–6–2 type locomotive with its most important parts numbered.

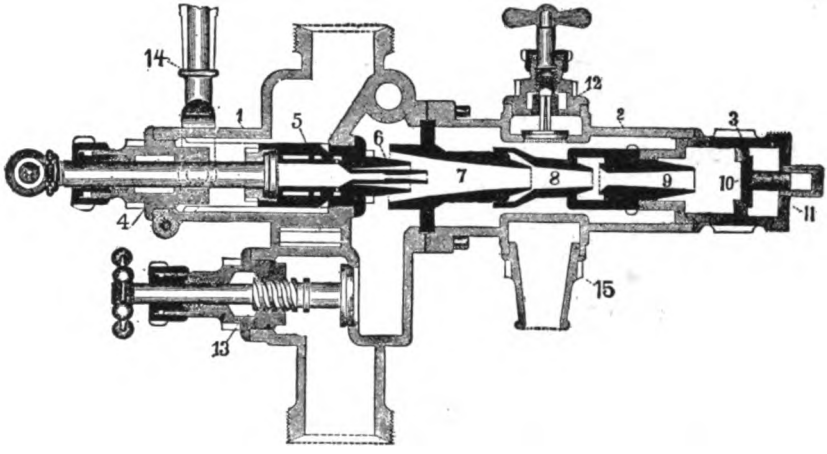

FIG. 75.—The Ohio locomotive injector. Sectional diagram (Standard A).

Lubricators.—The following illustrates, describes, and names the important parts of the Detroit, Nathan, and Chicago locomotive lubricators:

Figures 78 to 83, inclusive, show cuts of the Detroit Locomotive Lubricators, Nos. 21 and 22, followed by numbered reference lists of their most important parts.

These two lubricators are practically the same in design and construction, except that the No. 22 has an added appliance termed the *Oil Control Valve.* This valve is located in the oil passage between oil reservoir and sight feed valves. After once properly adjusting the regulating valves, the feeds can be stopped, started and the rate diminished by its use, thus doing away with the necessity of shutting off feed regulating valves at terminals or when refilling and also the necessity of readjusting feed valves.

The oil control valve has a lever handle and an indexed plate. By moving the handle a half turn from "closed" position all feeds

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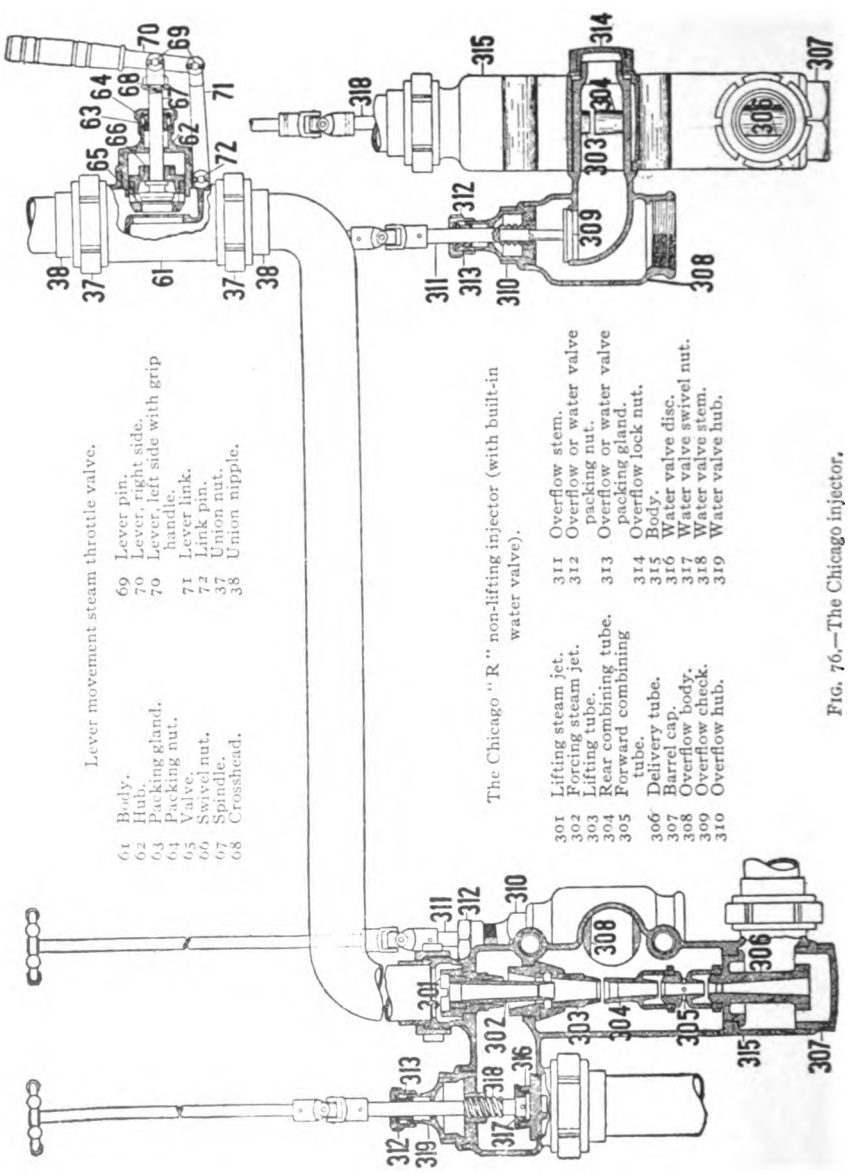

FIG. 76.—The Chicago injector.

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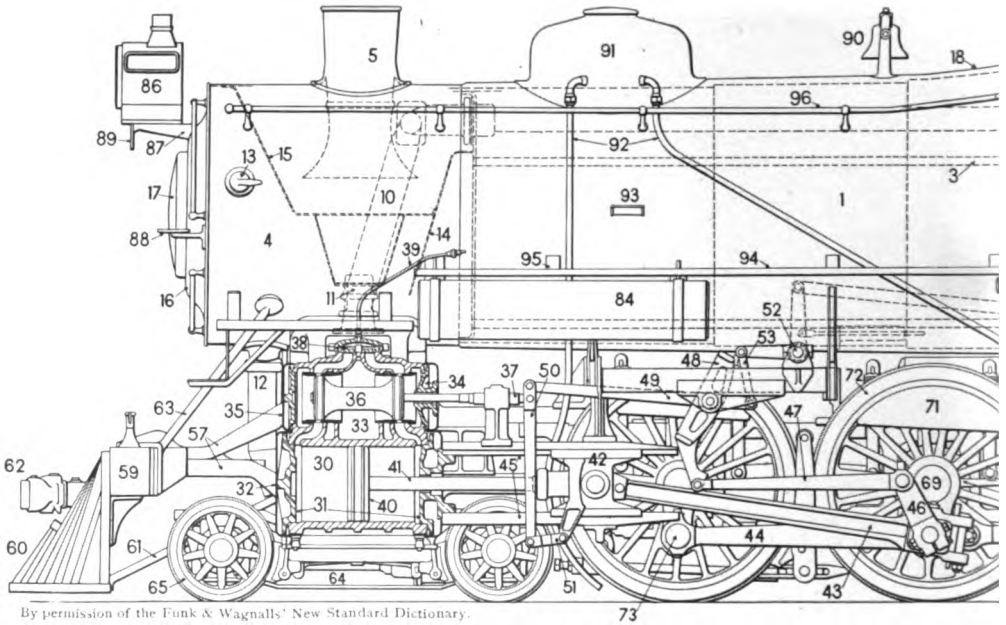

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FIG. 77.—Outline of 4-

1 Boiler.
2 Firebox.
3 Fire tube.
4 Smoke box.
5 Smoke stack.
6 Dome.
7 Throttle chamber.
8 Throttle lever.
9 Dry pipe.
10 Steam pipe.
11 Exhaust pipe.
12 Spark chute.
13 Spark cleaning hole cap.
14 Diaphragm or deflector plate.
15 Spark-arrester netting.
16 Smoke box front.
17 Smoke box door.
18 Boiler lagging jacket.
19 Whistle.
20 Whistle lever.
21 Safety valve dome.
22 Safety valve.
23 Fire door.
24 Shaking grates.
25 Drop grate.
26 Shaking grate rod.
27 Drop grate lever.
28 Ash pan.
29 Ash pan dump bell crank.
30 Cylinder.
31 Cylinder heads.
32 Cylinder head casing.
33 Valve chamber.
34 Valve chamber head.
35 Valve chamber head casing.
36 Valve (piston).
37 Valve stem.
38 By-pass valve.
39 Oil pipe.
40 Piston.
41 Piston rod.
42 Crosshead.
43 Main rod.
44 Side rod.
45 Guides.
46 Eccentric crank arm.
47 Eccentric ro
48 Link.
49 Radius rod.
50 Lap and le
51 Lap and le nector.
52 Lift shaft.
53 Radius rod
54 Reverse lev
55 Reach rod.
56 Main frame
57 Front frame
58 Rear frame.
59 Front bump
60 Pilot.
61 Pilot brace.

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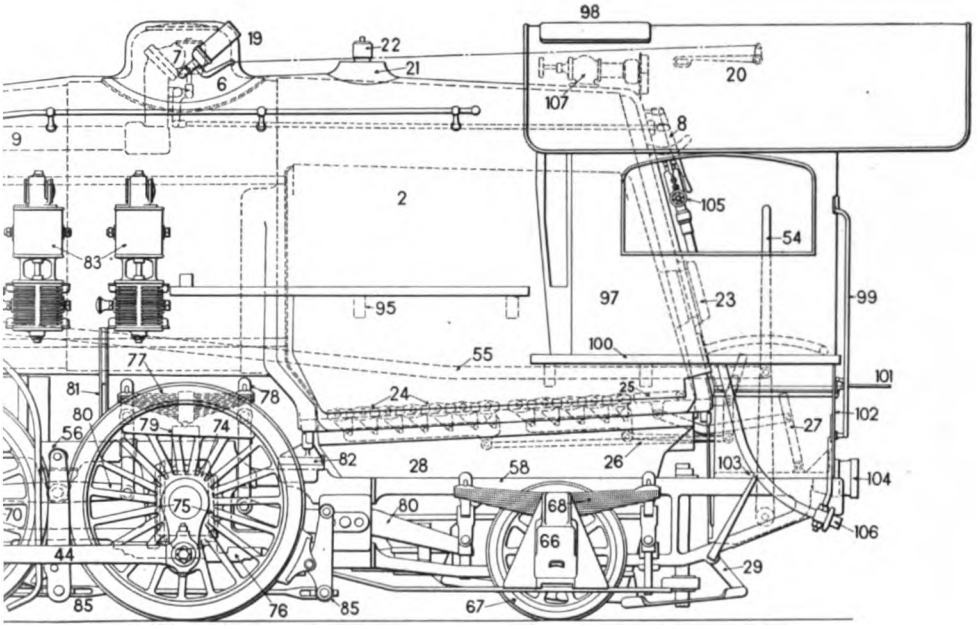

5-2 type locomotive.

d.	62	Coupler.	76	Frame pedestal brace.	92	Sand pipes.
	63	Smoke box bumper brace.	77	Driving spring.	93	Step.
	64	Front truck pedestal tie bar.	78	Driving spring hanger.	94	Running board.
d lever.			79	Driving spring saddle.	95	Running board bracket.
d lever con-	65	Truck wheel.	80	Driver equalizer.	96	Hand-rail.
	66	Trailer truck oil box.	81	Expansion plate.	97	Cab.
	67	Trailer wheel.	82	Firebox expansion brace.	98	Cab ventilator.
anger.	68	Trailer truck spring.	83	Air pumps.	99	Cab hand hold.
r.	69	Driving axle.	84	Main reservoir.	100	Cab floor.
	70	Driving wheel center.	85	Driver brakes.	101	Apron.
	71	Driving wheel counter-balance.	86	Headlight.	102	Cab bracket.
s.			87	Headlight bracket.	103	Deck plate.
	72	Driving wheel tire.	88	Step.	104	Back chafing plate.
er.	73	Crank pin.	89	Number plate.	105	Injector.
	74	Driving box.	90	Bell.	106	Supply pipe.
	75	Driving box shoes.	91	Sandbox.	107	Steam turret.

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will be opened; one-quarter turn the feed to the air pump only, and *vice versa*. With this lubricator the feeds should be adjusted to the maximum rate required by the locomotive during the day's run or trip, which can be diminished for lighter service by throttling with the oil control valve. After the feed valves have once been properly adjusted for any particular service they should not be changed unless conditions arise that require an increased quantity of oil.

The method of applying sight feed glasses to Detroit Lubricators Nos. *21* and *22* is apparent from the actual size illustration shown in Fig. 84.

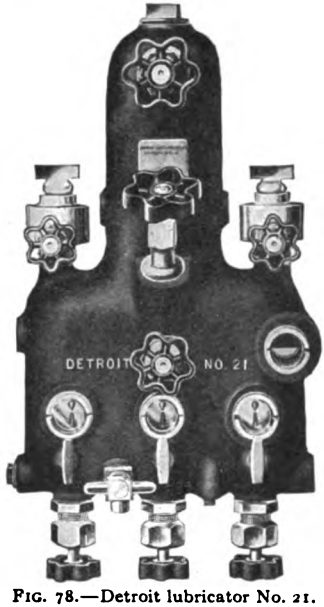

FIG. 78.—Detroit lubricator No. 21.

Figures 85 and 86 show cuts of a Nathan Bull's Eye Lubricator, followed by a list of its important parts.

The method of applying sight feed glasses to the Nathan Bull's Eye Lubricators is shown in Fig. 87.

Figures 88 and 89 show cuts of the Chicago Locomotive Lubricators, Classes C (Three Feed) and D–4 (Five Feed), followed by a list of important parts.

Power Reverse Gear.—Owing to the size and weight of the parts of valve gear of articulated and other types of heavy locomotives, it has become the practice to apply a power operated reversing gear. The following is a description of the power reversing gear applied to articulated locomotives built by the American Locomotive Company.

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This reversing gear is an engine consisting of two cylinders, one an air cylinder and the other filled with oil. The two cylinders are set one ahead of the other, and are usually bolted to the underside of the mud ring or some other convenient location.

Fig. 90 shows the arrangement and construction of this mechanism. In this case, the forward one is the air cylinder, and the rear one the

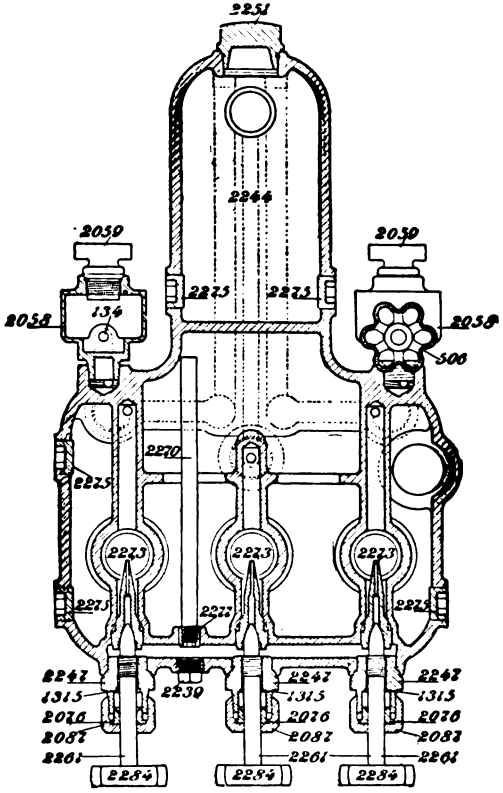

FIG. 79.—Detroit lubricator No. 21.

oil cylinder; although this arrangement is usually reversed and can be made whatever the circumstances require. In any arrangement, both pistons are mounted on a common piston rod which is connected to either the main reverse lever, or, as in the illustration, to an extension of the reverse shaft arm.

Between the two cylinders are the packing boxes for the common piston rod; and there is also a stuffing box at the air end of the

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cylinder for the rod connecting the piston with the reverse lever or shaft, as the case may be. Both pistons are packed with leather pack-

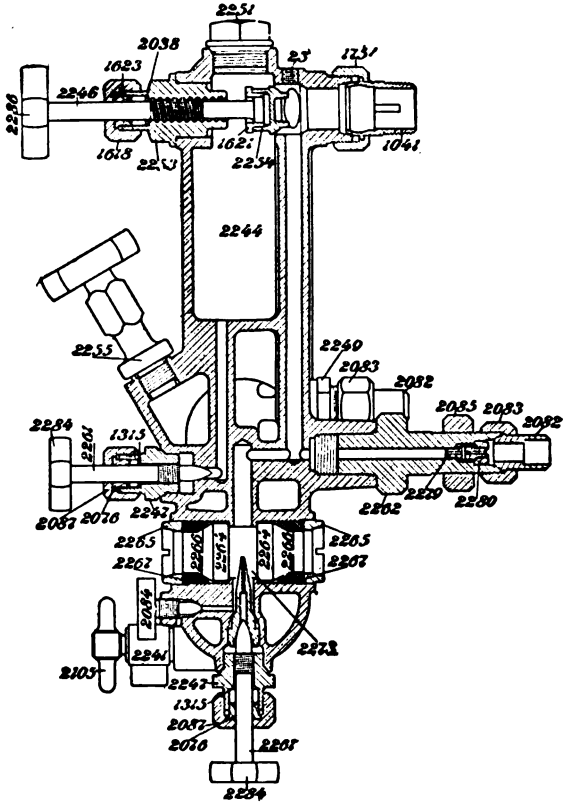

FIG. 80.—Detroit lubricator No. 21.

Legends for Figures 78, 79 and 80.

134	Hand oiler and water feed stem with handle.	2076	Feed stem packing gland.	2255	Filler plug.
306	Hand oiler valve handle.	2082	Tail pipe.	2261	Feed valve stem.
1041	One-inch tail pipe.	2083	Tail nut.	2262	Support arm.
1294	Hand oiler stem washer.	2084	Vent stem.	2264	Sight feed and gauge glass.
1315	Feed stem ring.	2085	Support arm jamb nut.	2265	Feed glass packing ring.
1618	Steam valve packing nut.	2087	Feed valve stem nut.	2266	Sight feed and gauge glass rubber packing.
1621	Steam valve disc lock nut.	2105	Drain stem.	2267	Feed glass washer.
1623	Steam valve packing gland.	2238	Water check stop.	2270	Oil tube.
1754	One-inch tail nut.	2241	Drain valve body.	2273	Feed nozzle.
2038	Steam valve packing ring.	2246	Steam valve stem.	2277	Oil tube bushing.
2058	Hand oiler body.	2247	Feed valve center piece.	2279	Air pump choke.
2059	Hand oiler filler plug.	2249	Tail pipe center piece.	2280	Air pump choke seat.
		2251	Condenser plug.	2284	Regulating valve handle.
		2253	Steam valve center piece.	2286	Steam valve handle.
		2254	Steam valve disc.	2329	Hand oiler center piece.

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ing, that in the air cylinder being held out by spring rings. The valves of both cylinders are conical, that for the air cylinder having four openings in addition to the exhaust cavity, while the oil cylinder valve has two crossed passages.

The valves of the air and oil cylinders are operated by an auxiliary reverse lever (R) to which they are connected by a rod. This lever

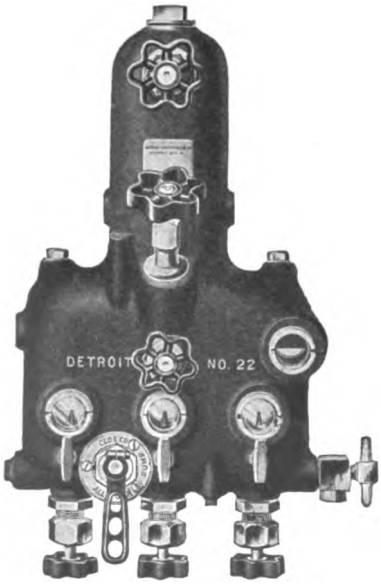

FIG. 81.—Detroit lubricator No. 22.

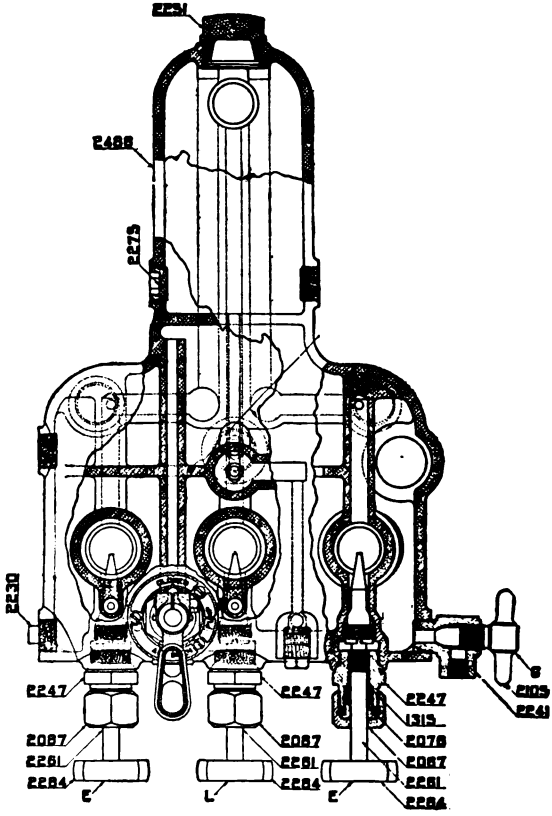

FIG. 82.—Detroit lubricator No. 22.

is pivoted on the main lever (Q) at the point (W). It is provided with a latch with teeth that fit in a quadrant in the same manner as the main lever. This latch is so interlocked with the latch of the main reverse lever (Q) that raising the former raises the latter, which cannot drop again unless the main reverse lever (Q) is in its normal position relative to the auxiliary lever (R).

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The levers are so designed that, when the two latches are lifted, the auxiliary reverse lever (R) is allowed sufficient movement about its pivot point (W) (limited by lugs on the main reverse lever latch) to give a full opening of the valves of the air and oil cylinders.

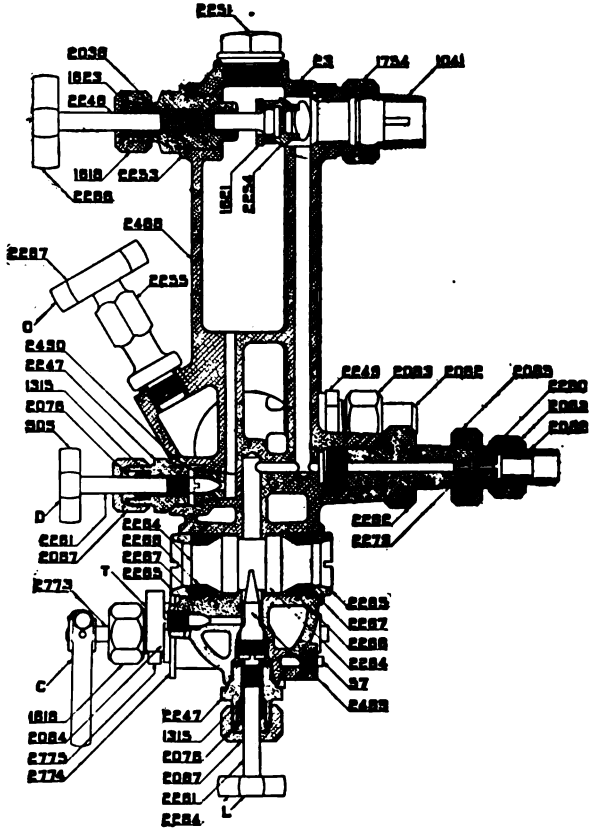

FIG. 83.—Detroit lubricator No. 22.

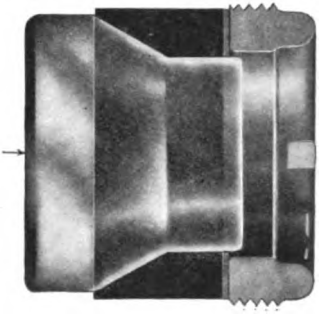

FIG. 84.—Sight feed glass.

2084 Vent stem.
2087 Feed valve stem nut.
2105 Drain stem.
2238 Water check stop.
2241 Drain valve body.
2246 Steam valve stem.
2247 Feed valve center piece.
2249 Tail pipe center piece.
2251 Condenser plug.
2253 Steam valve center piece.
2254 Steam valve disk.
2255 Filler plug.
2261 Feed valve stem.
2264 Sight feed glass.
2265 Feed glass packing ring.
2266 Feed and gauge glass rubber packing.
2267 Feed glass washer.
2279 Air pump choke.
2280 Air pump choke seat.
2284 Feed valve handle.
2286 Steam valve handle.
2287 Filler plug handle.
2489 Feed nozzle.
2490 Water valve seat.
2773 Control valve plug.
2774 Control valve dial plate.
2775 Control valve center piece.
2822 Control valve handle.

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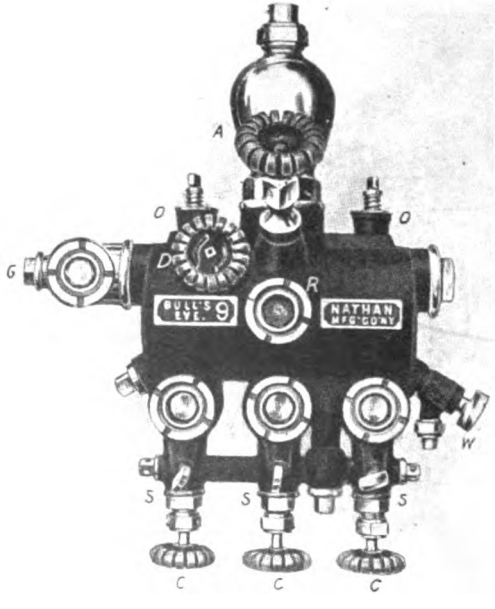
When a change in cut-off is desired, the latch of the auxiliary lever (R) is released, which also unlatches the main reverse lever (Q). If the main reverse lever (Q) is to be thrown ahead, the auxiliary lever is moved forward about its pivot point (W); and back, if it is desired to move the main lever in that direction. The movement of the auxiliary lever (R), forward or back, swings its lower end (Y),



Front view.

FIG. 85.—Nathan lubricator, bull's-eye type.

A. Filling plug.
D. Water valve.
O. O. Hand oilers.
S. S. S. Sight-feed drain valves.
C. C. C. Regulating valves.
G. Gauge glass.
R. Reserve glass.
W. Waste cock.

which operates the valves of the air and oil cylinders, and the valve gear is moved in the desired direction.

For instance, when the auxiliary lever is pushed forward, its lower end (Y) is drawn back. This turns the valve of the air cylinder so that the air is admitted through the air inlet (13) to the front of the piston, and the exhaust port (14) establishes communication between the rear end of the air cylinder and the exhaust to the atmosphere. At the same time, the crossed passages of the oil cylinder valve are so turned as to allow the oil in the cylinder to flow from one end to the

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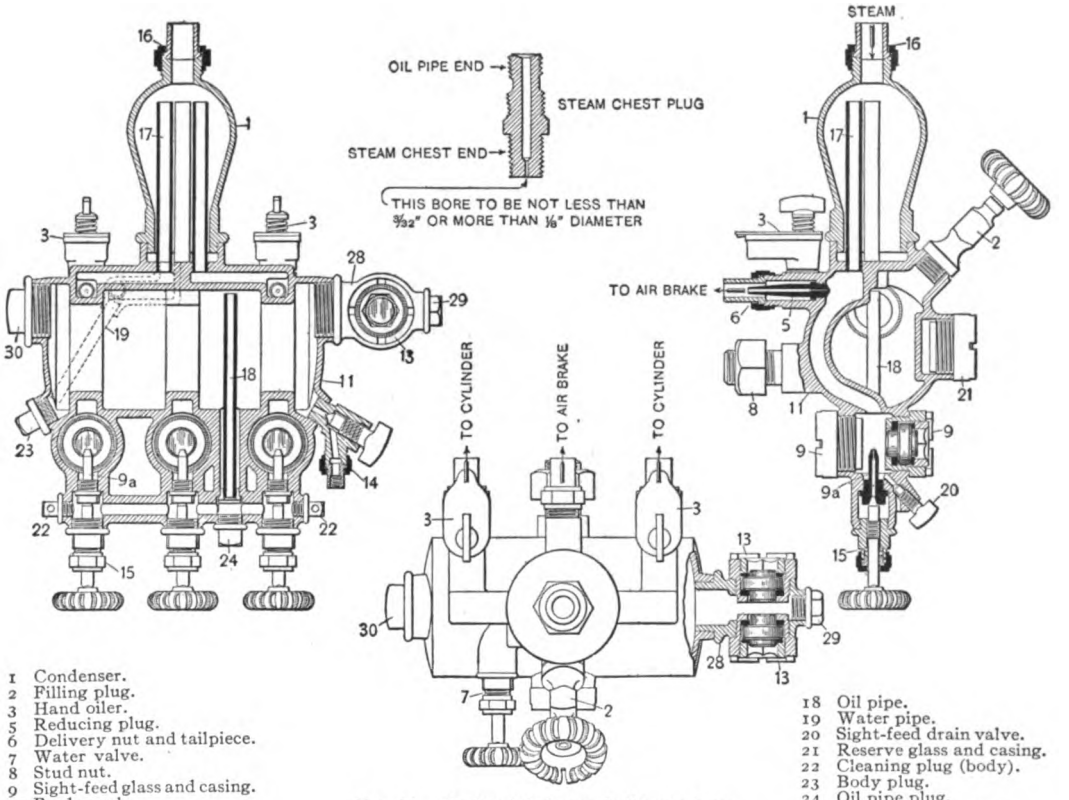

1 Condenser.
2 Filling plug.
3 Hand oiler.
5 Reducing plug.
6 Delivery nut and tailpiece.
7 Water valve.
8 Stud nut.
9 Sight-feed glass and casing.
9a Feed nozzle.
11 Body.
13 Gauge glass and casing.
14 Waste cock.
15 Regulating valve.
16 Top connection.
17 Equalizing pipe.
18 Oil pipe.
19 Water pipe.
20 Sight-feed drain valve.
21 Reserve glass and casing.
22 Cleaning plug (body).
23 Body plug.
24 Oil pipe plug.
28 Gauge glass bracket.
29 Cleaning plug (gauge glass).
30 Gauge glass cap.

FIG. 86.—Nathan lubricator, bull's-eye type.

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other. The air and oil pistons thus move back and the valve gear is moved forward. The slow flow of the oil in the oil cylinder prevents the too rapid movement of the reverse lever (Q).

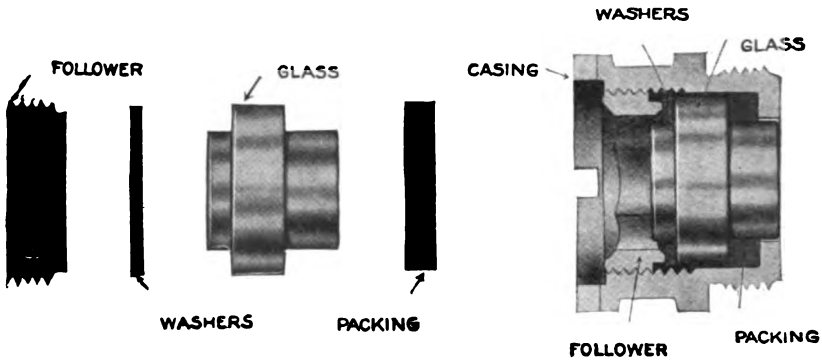

FIG. 87.—Method of applying sight-feed glasses.

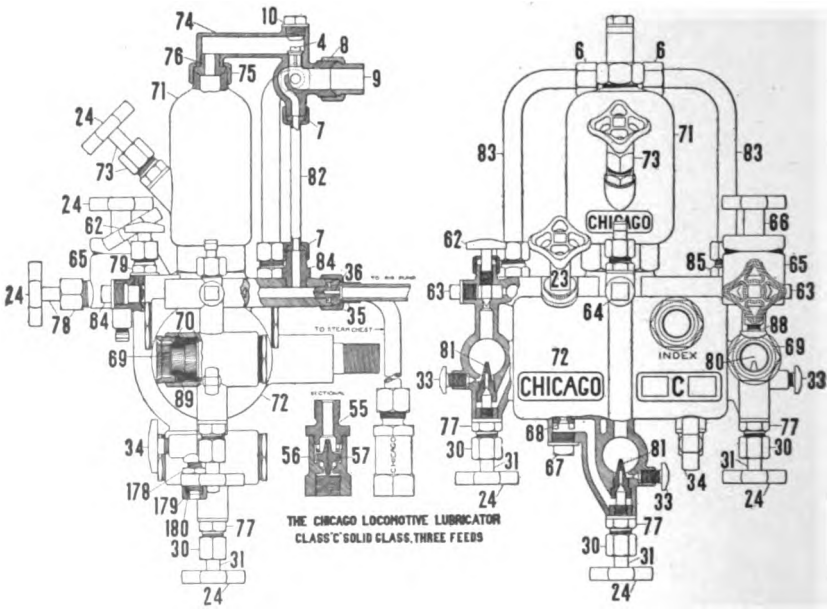

FIG. 88.—Chicago class C, three feeds, with solid glasses.

The auxiliary lever (R), being pivoted on the main reverse lever (Q), moves with the latter, and when the gear is to be changed must be kept in motion until the desired notch in the quadrant is reached

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and then latched. By stopping the movement of the auxiliary lever, the gear automatically moves the main reverse lever up to its normal position relative to the former, when it also latches, as already stated.

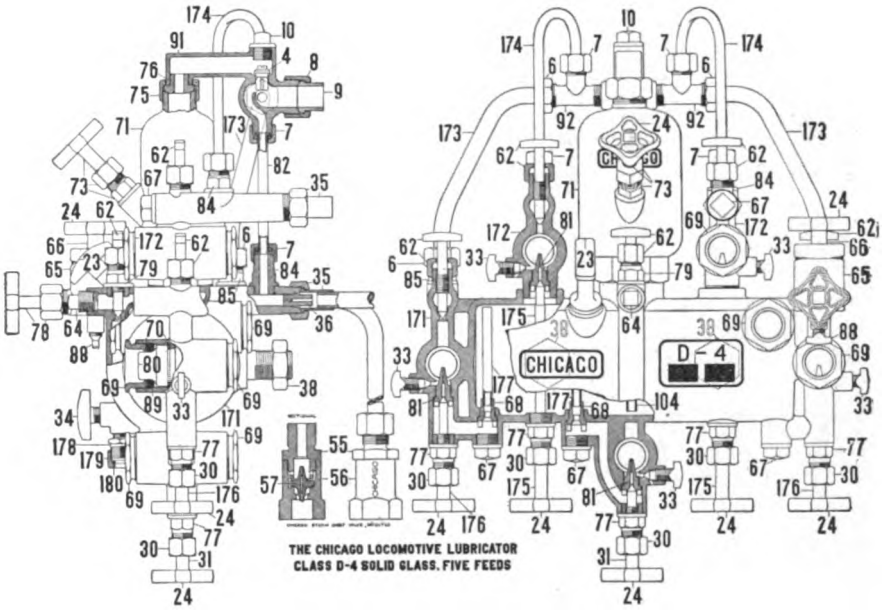

FIG. 89.—Chicago class D-4, five feeds, with solid glasses.

4 Check valve.
23 Piller plug.
24 Handle for valve stems.
31 Feed valve.
33 Drain valve.
34 Drain valve plug for oil bowl.
36 Choke plug for air pump feed.
51 Feed valve with regulating attachment, complete.
54 Auxiliary handle for regulating attachment.
55 Cap for steam chest valve No. 3.
56 Casing for steam chest valve No. 3.
57 Valve for steam chest valve No. 3 or No. 3-A.
62 Pressure valve and nut.
65 Auxiliary oil cup.
66 Auxiliary oil cup filler plug.
69 Packing nut for glass.
70 Follower ring and washer for solid glasses.
71 Condenser.
72 Oil bowl. (Three feed.)
73 Water valve, complete.
78 Auxiliary oil cup feed valve, complete.
80 Solid glasses for feed pocket (sight-feed chamber or index).
81 Feed cone.
82 Circulating (equalizing) pipe complete for air pump.
83 Circulating (equalizing) pipe complete for steam chest.
88 Auxiliary oil cup drain valve.
104 Water pipe in condenser.
171 Oil bowl (5-feed only).
173 High pressure (equalizing) circulating pipe, complete.
174 Low pressure (equalizing) circulating pipe, complete.

This also automatically closes the valves of both the air and oil, giving both an oil and a positive lock to the gear.

Except in case of lack of air pressure or any accident to the power reversing gear, the valve gear is handled entirely by the auxiliary reverse lever (R). For this reason the latest practice of the American Locomotive Company is to cut off that portion of the main reverse

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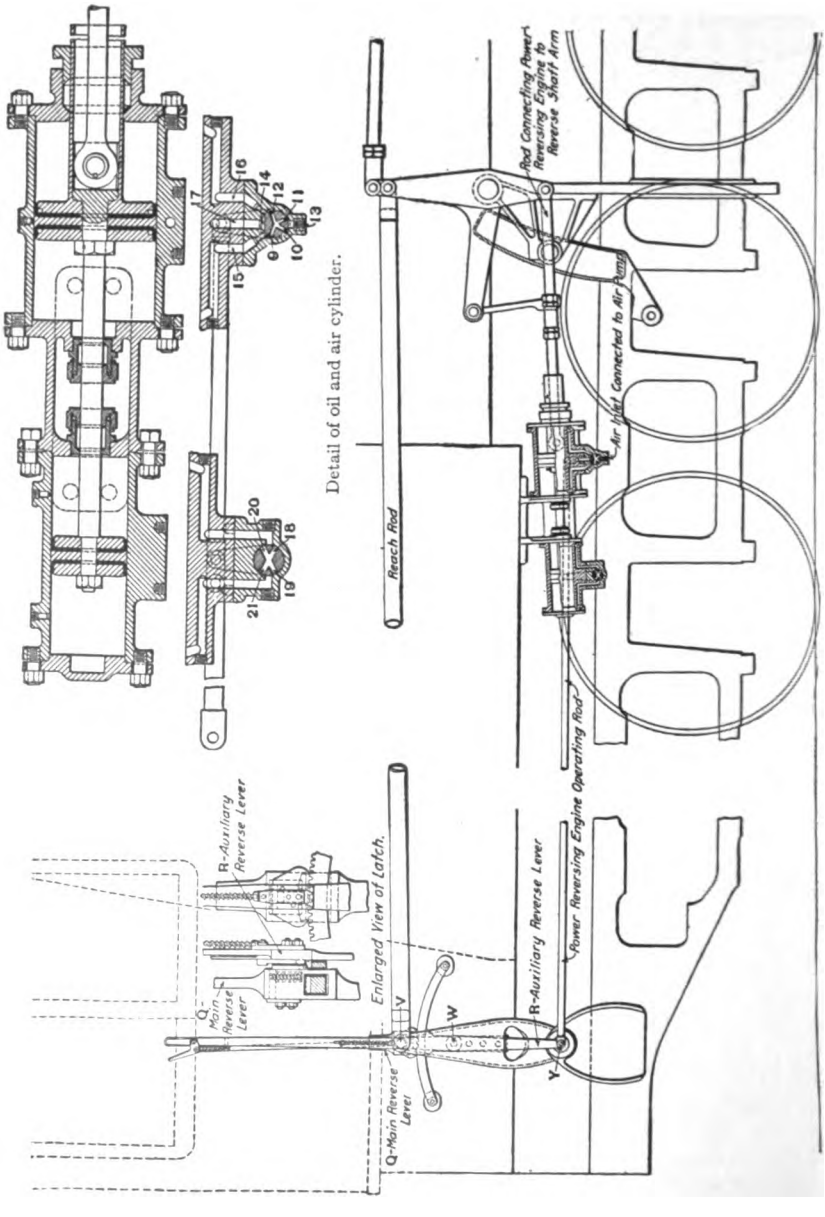

FIG. 90.—Power reverse gear.

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lever (Q) which ordinarily projects above the deck of the cab, thus leaving more room for the engineer. A separate handle is provided for the main reverse lever, which may be easily applied in case of accident to the power reversing gear.

It is important that the air and oil valves be properly set so that the valve openings and cylinder ports match up properly in the different positions. For example: A quarter of a turn of the oil valve one way

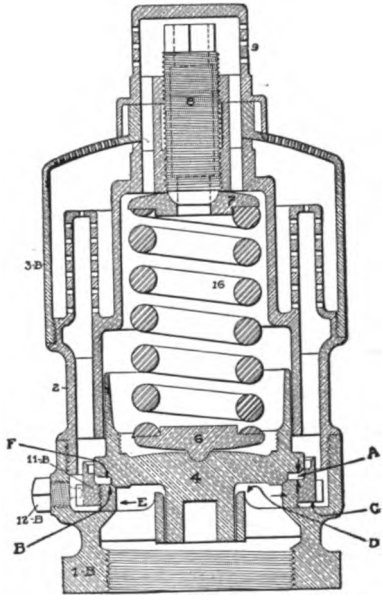

FIG. 91.—Coale muffled safety valve.

1-B	Base.	6	Lower spring button for plain valve.	9	Cap for plain valve.
2	Spring case.	7	Upper spring button.	11-B	Improved adjusting ring.
3-B	Modified muffler dome.	8	Spring bolt.	12-B	Bolt for locking adjusting ring
4	Valve.			16	Valve spring.

or the other would result in the valve being blanked instead of open when the auxiliary lever (R) was moved about its pivot point. The gear could not, then, be operated, as the oil could not circulate from one end of the oil cylinder to the other. If the power reversing gear fails to operate when the valves are supposedly opened and nothing has happened to the air supply, first examine the valves to see that they are in their proper position.

The function of the oil cylinder is to prevent the too rapid movement of the reversing gear when a change of cut-off is made, and it is imperative that this cylinder be always kept full of oil.

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Transverse Equalizer.—An equalizer that connects the spring suspensions on two sides of a locomotive.

Safety Valve.—Fig. 91 shows a sectional view of the Coale Muffled

FIG. 92.—Crosby muffled pop safety valve.

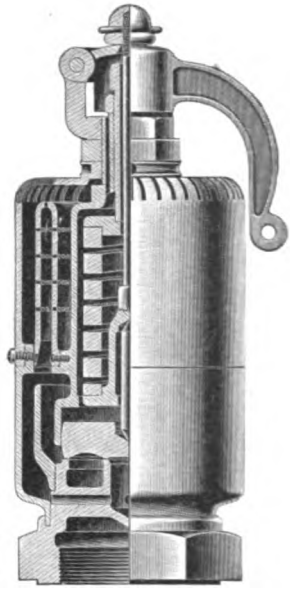

FIG. 93.—Crosby muffled pop safety valve.

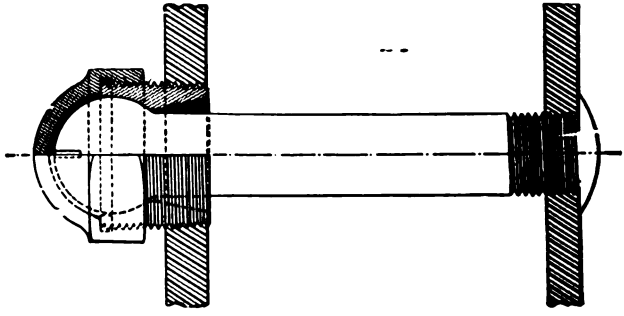

FIG. 94.—Tate flexible staybolt.

Safety Valve, followed by a list of its parts. Figs. 92 and 93 show exterior and sectional views of the Crosby Muffled Pop Safety Valve.

Staybolts.—Fig. 94 shows a sectional view of the application of the Tate Flexible Staybolt.

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PART XI

QUALIFICATIONS AND RESPONSIBILITIES

Operating Conditions, Qualifications and Responsibilities, Selection of Engineers and Firemen, Co-operation, Health and First Aid, Questions

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OPERATING CONDITIONS.

As stated in the preface, this book treats specifically on the arts of locomotive running and firing. In the main, the matter has been presented in a direct, impersonal manner; but now, before closing, it seems fitting to become a little less formal, to say something about the men that operate locomotives, how they are selected for the positions they fill, the qualifications they should possess, their responsibilities; to mention some of the benefits mutually accruing to the men and the companies employing them through the co-operation of engineers and firemen in the performance of their duties, and to advise on health preservation and aid to injured persons.

The occupations of locomotive running and firing are now generally recognized as trades, for to successfully and efficiently operate a locomotive, engineers and firemen must possess a high degree of skill and knowledge, which can be acquired only by actual experience and diligent study of relating subjects.

The time was when the engineer was required to be somewhat of a mechanician, had to be capable of making repairs and mechanical adjustments, and maintain the locomotive's physical condition. But this has changed, these features of locomotive operating now belong to another department. Usually the locomotive is practically complete in its appointments and in serviceable condition when placed in charge of the engineer and fireman, and they make the prescribed trip or run with it as skilfully and economically as they are capable of and operating conditions permit. Ordinarily no repairs or adjustments to the machinery are necessary when the locomotive is placed in their charge. But even when disorder or breakdown disables the locomotive on the road, repairs are not attempted by the engineer and fireman, but some temporary expedient is usually improvised for its movement to a terminal or shop where repairs can be made.

The engineers and firemen of modern locomotives have property of enormous value, directly and indirectly, in their charge, and the lives and limbs of many persons depending upon their skill and competency, and so railroad companies are very exacting in their requirements as to the physical and mental attributes, moral habits and performance records of these men, and select men with greatest care from applicants aspiring to those positions.

QUALIFICATIONS AND RESPONSIBILITIES.

The following are a few of the more important essentials that qualified and capable engineers and firemen should satisfactorily meet:

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1. The engineer should have an exact knowledge of the locomotive, and some knowledge of the nature and construction of steam engines generally. He should be perfectly familiar with the management of the boiler, the running of the locomotive, and the way of keeping its working parts in good condition; also with the physical characteristics of the parts of the railroad on which he runs, the rules that govern the running of trains and the established signal system. In caring for the locomotive, he should preserve cleanliness and order, and in the use of fuel and supplies should manifest the greatest care and economy.

2. Engineers and firemen should carry out exactly and cheerfully the regulations of the service, or the instructions given by special orders from superior officers. Towards superior officers their behavior should be respectful and obliging.

3. The engineer should, as far as possible, endeavor to instruct the fireman that accompanies him, making him familiar with the construction and management of the locomotive, he should see that the fireman does his work strictly in accordance with instructions.

4. It is the fireman's duty to follow the engineer's instructions strictly, and in the event of sudden disability of the engineer he should stop the locomotive immediately and signal for help.

5. Engineers and firemen should keep themselves thoroughly informed of the progress in improvement and development of locomotives by reading suitable books and periodicals.

That the business of transportation may be systematically conducted and trains safely and promptly moved, all railroad companies have effective a code of rules governing the respective duties of their employees. These rules, compiled and issued in book form, usually termed *the book of rules,* are designed primarily to control train movements, and provide for incidental contingencies and emergencies that may arise under known conditions. However, from time to time new conditions arise; changes in grades, track alignment, or signals are made; new apparatus installed, and new methods of operation instituted, necessitating the issuance of new rules, usually termed *special instructions.* It is customary to issue them as bulletins called *general orders* and *notices,* posting them on bulletin boards at offices of engine-houses and other places where employees report for duty.

Nowadays engineers and firemen rarely come in personal contact with any of the officers of a railroad company higher than the operating staff of a division. A division, as is generally known, is a specified part of a railroad, under the authority of a superintendent, who retains a staff of subordinate officers that head the several operating departments. While there is some variation in practice, usually engineers and firemen report to and receive their instructions from the Road Foreman of Engines (Travelling Engineer) or the Master Mechanic. On the

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road, engineers must also obey the orders of the Train Master; and those of the Engine-house Foreman while at engine house. While on duty firemen are in charge of and should obey the instructions of engineers.

SELECTION OF ENGINEERS AND FIREMEN.

The Road Foreman of Engines (Travelling Engineer) or Master Mechanic usually employs men for the position of firemen, though this is sometimes done by special employing officers. The fireman of the present makes the engineer of the future. When railroad companies employ men for the position of fireman, they do so with not only the intention of making use of their services as firemen, but with the further purpose of training them up to the position of engineer. On this account, young men, between the ages of 19 and 26 years, are usually selected for the position of fireman, for generally several years elapse before promotion to engineer comes, and if they begin as firemen late in life, the probabilities are that they will be well into or past the most efficient time of life by the time a settled position as engineer has been secured. There is some diversity of practice on the various railroads in selecting men for the position of fireman, though as a general rule applications are accepted from men of all occupations, little or no preliminary training being deemed necessary before putting them on a locomotive as fireman. Applicants must be able to read, write legibly, make arithmetical calculations, and furnish character recommendation from previous employer or some reputable person. Meeting the foregoing requirements, personality and recommendations being satisfactory, applicants are usually required to satisfactorily pass examinations as to hearing, eyesight and color perception, and physical condition, before being assigned to work.

The prevailing method of selecting locomotive engineers is to promote eligible and efficient firemen as needs require, for passing through the occupation of fireman is the only way men can obtain practical knowledge of locomotive running. While it is not actually essential that engineers and firemen be well informed in technicalities, as locomotive operating and railroad work can be learned only by experience, yet it is necessary for these men to be well informed on subjects that pertain to their especial duties; and that it may be known that they do possess such knowledge all railroad companies now require examinations that must be satisfactorily passed in order to be promoted and sometimes that positions may be retained.

The list of questions at the end of this Part is an example of the examination questions asked firemen when candidates for promotion, or of engineers applying for positions as such. These questions may not be literally the same as those asked by the examiners of the

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different railroads, but they give a good idea of the nature of such examination questions and also the kind of knowledge respecting his business that an engineer is required to be possessed of. Answers to these questions are not given, but as they are compiled in the same order as relating matter in the text of the book, it is only necessary to refer to the subject matter.

CO-OPERATION.

To obtain efficient service from locomotives, economy in consumption of fuel and supplies, satisfaction and comfort to operatives, nothing is so important as co-operation between engineers and firemen in the performance of their respective duties. Engineers should observe firemen in their work, prompt them when necessary; advise them in advance of a change in running conditions that will either increase or decrease the amount of steam required, and so operate the locomotive as to enable the firemen to maintain a nearly constant steam pressure. Firemen should assist their engineers in preparing, inspecting and maintaining the locomotive, should observe their method of operating it, and so fire the locomotive that the required amount of steam will be generated with the least consumption of fuel.

Railroad companies generally realize that efficient operation of locomotives is largely in the hands of their engineers and firemen, and they are appealing to them directly, intelligently directing their efforts by presenting compelling and easily understood reasons showing the potent effect of a little extra care and watchfulness, and that the best results in fuel economy are secured through the co-operation of locomotive crews rather than through any special improvement in existing conditions or in the quality of fuel used.

In order to convince their men that economy in fuel consumption can be effected by the co-operating of locomotive crews, the Lehigh Valley R. R. recently gave a practical demonstration, which was the running through without change on a heavy fast passenger train one locomotive, in charge of an engineer and fireman who had a record for fuel economy, between Buffalo and Jersey City, a distance of 446.6 miles.

The following table gives a comparison of some of the figures taken from this test run and corresponding figures for the year ending June 30, 1910:

	Coal per pass. train mile	Coal per pass. car mile	Shovelfuls per mile at 14 lbs.
Test Train	67.33 lbs.	7.134 lbs.	4.8
Average 1910	132.2 lbs.	24.4 lbs.	9.4

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From the above it can be appreciated what is possible by careful manipulation of a locomotive by its engineer and fireman. The total amount of coal used between Buffalo and Jersey City was 15 tons and 70 pounds, while the amount of coal consumed usually on this run is between 25 and 30 tons.

In connection with fuel economy, co-operation of engineers and firemen and smoke prevention, the *American Engineer and Railroad Journal* recently remarked the following:

"It has been well said, 'The man behind the scoop, when properly educated, is the most efficient coal saver in existence,' and this is true of the operative conditions of every locomotive on every railroad burning soft coal. The matter lies largely in the hands of the engineer and fireman, and the engineer as well as the fireman. Better results can be accomplished by the properly instructed and rightly disposed crew, without any contrivance to prevent smoke, than can be obtained by the most elaborate mechanical provisions without the exercise of brains and interest by the men in the cab; and it is probable that the larger proportion of good results obtained, during tests of various devices to save fuel and prevent smoke, really result from awakened interest and harmonious co-operation of the engineer and fireman."

HEALTH AND FIRST AID.

In the performance of their duties engineers and firemen should always act with the greatest caution, and never rush carelessly into danger. They should bear in mind that they have a great responsibility upon them, and that it is not alone their own well-being and life that is at stake in the event of accident, but that by carelessness or indifference they may injure or kill the helpless persons that are committed to their care. They should study how to care for themselves under all conditions of railroad life; for these positions are fatiguing and very exacting, requiring men of strong physique and clear brain, men that can readily recuperate from weariness and exertion. They should understand the best manner of clothing themselves to suit the several seasons of the year, being especially careful to eat nourishing foods, and should abstain from the use of intoxicating drinks as a beverage at all times, as they surely undermine the physical and mental strength of habitual users.

The man who can be relied upon at a time of accident to himself or to his fellow-man will some day rejoice at his knowledge. In this connection, the following are a few practical hints along the line of First Aid to the Injured:

Keep cool.

Send for a physician, giving him as near as possible the character of the injuries.

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Keep the crowd away, so as to insure plenty of fresh air.

If the injured person is fast in wreckage, use the utmost care when removing him so as not to cause further injuries.

Examine injuries carefully before doing anything, and don't touch an open wound with the hands, nor attempt to remove dirt nor apply unclean dressings of any kind, as infection may be introduced by so doing.

Stretcher, Use Of.—A stretcher can be used as a cot. It requires three men to place a person properly on a stretcher. Set up the stretcher; place it alongside the injured person. The three men should then stand at the side of the injured person away from the stretcher; one should place his hands under the head and shoulders, the other under the hips and the third take charge of the injured part; lift him up and lay him gently on the stretcher.

Hemorrhage.—To arrest hemorrhage, place compresses on the bleeding part and secure firmly; if bleeding continues, apply more compresses and more pressure until bleeding ceases. If this fails, tie a bandage around the limb between the point of hemorrhage and the body, and twist tightly with a stick until bleeding stops. Then secure bandage. Do not use tobacco quids or spider webs, as they can cause blood poisoning. Apply warmth to body if skin is cold.

Shock.—Shock is a condition of almost complete absence of the signs of life, such as sighing respiration, pale, cold, clammy skin, etc. Don't give whiskey or any other stimulants or drugs; the principal requirements are internal and external heat, by means of hot coffee, hot milk, and other hot drinks, and the application of heat by means of blankets, hot water-bottles, hot bricks, etc. In case of apparent drowning and electrical shock, use artificial respiration.

Fracture.—Broken bones should be treated with splints, secured in position by triangular and other bandages. The splints should reach from below the lower joint to the one above the fracture. Folded newspapers, pieces of board, heavy pasteboard or anything sufficient to prevent movement of the broken ends of bones upon each other will answer. If skin is broken by bone, cover with clean compress.

Dislocations.—Keep patient comfortable, and keep part immovable. Do not attempt to replace limb.

Burns and Scalds.—Do not use engine oil. Do not touch the burned part. Remove clothing from burn always by cutting; do not tear it away. If it sticks closely place over it two or three compresses, wetting with moderately warm water. No stimulants; treat as for "shock." Cover with "carron oil" (which is equal parts of raw linseed oil and lime water) or "baking soda."

The following is another preparation recommended for treating burns and scalds:

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Twenty per cent. solution of boracic acid, in vaseline, with a small amount of oil of Cade as a preservative.

This preparation should be applied to a burn or scald without injury to the wound, and only in quantity sufficient to protect it from action of the air, for it should be thoroughly understood that this preparation has no healing properties, but simply serves to allay pain until the patient can be treated by a physician.

To Remove a Cinder from Eye.—The patient should look down; the lashes are used to pull the upper lid forward and downward; then it is pulled away from the globe of the eye and upward over the point of the thumb of the other hand, or over the blunt point of a pencil. Remove the cinder with a clean piece of cloth or cotton after you have turned back the lid. Do not use a dirty match or toothpick, as many an eye becomes infected in this way, sometimes leading to its disease and loss of sight.

Unconsciousness.—Persons unconscious from any cause should be removed to a quiet place and laid upon the back. Keep every one away and let plenty of air get to the sick person. Loosen the clothing about the neck and abdomen. If the conditions are like shock, use same treatment.

Fits.—A person suffering from a fit should be kept quiet, on the back. Loosen the clothing about the neck and abdomen, and be careful he does not injure himself while in the fit.

Heat Exhaustion and Sunstroke.—In the former the skin will be cold and clammy, and the conditions will be same as shock; the same treatment will be required. In cases of sunstroke the body feels hot to the touch; is dry. Apply ice to the abdomen, head and other parts of the body by rubbing with pieces of ice or cracking the ice and putting it in cloths over the parts named above.

QUESTIONS.

Part I.

Q. Describe the steam Locomotive.
Q. How many classes of locomotives are in general use?
Q. Describe a simple locomotive.
Q. Describe a compound locomotive.
Q. What types of valve gears are in general use?
Q. Give a short description of the construction of a locomotive boiler.
Q. How is the weight of a locomotive distributed?
Q. What limits the power developed by a locomotive boiler?
Q. What advantages are obtained by compounding?
Q. On what does tractive effort depend?
Q. How is the power of a locomotive expressed?
Q. How is tractive effort calculated?
Q. How is horse power calculated?
Q. How can the train weight a locomotive will pull be calculated?

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PART III.

Q. What is Matter?
Q. In what state or condition does Matter exist?
Q. What is Inertia?
Q. What is Energy?
Q. How many kinds of Energy exist? Define them.
Q. What does "Dynamics" treat of?
Q. What is meant by the term "Mechanics"?
Q. What is Force?
Q. What is Motion?
Q. What is Velocity?
Q. What is meant by "Momentum"?
Q. What is Work?
Q. What is a Unit of Work?
Q. What is meant by "Power"? Define Horse Power.
Q. What is meant by the Center of Gravity?
Q. What is meant by "Efficiency"?
Q. What is "Friction"?
Q. What is meant by the Co-efficient of Friction?
Q. What is Pressure? Absolute Pressure?
Q. What is meant by the term "Volume"?
Q. What is "Heat"?
Q. What is meant by the term "Temperature"?
Q. Is there any distinction between Heat and Temperature?
Q. What is "Sensible Temperature"?
Q. What is a "Unit of Heat"?
Q. What is meant by "Radiation of Heat"?
Q. What is meant by "Conduction of Heat"?
Q. What is an "Element"?
Q. What is meant by Affinity?
Q. What is a "Compound"?
Q. What is "Carbon"?
Q. What is "Oxygen"?
Q. What is "Hydrogen"?
Q. What is "Nitrogen"?
Q. How is "Water" formed?
Q. At what temperature does water reach its maximum density?
Q. What is "Carbon Monoxide"? How is it formed? Is its formation the result of incomplete combustion, and does its escape from a locomotive firebox result in loss of heat?
Q. What is "Carbon Dioxide"? Is it the product of complete combustion?
Q. What is the Atmosphere composed of?
Q. What is the pressure of the atmosphere?
Q. How can different coals be graded?
Q. What are the characteristics of the different grades of coal?

PART IV.

Q. What is Steam?
Q. What is meant by the term "Saturated Steam"?
Q. What is Superheated Steam?
Q. What is meant by "Latent heat of Steam"?
Q. What is Dry Steam? Wet Steam?
Q. How is steam formed?
Q. What is meant by "Expansion of Steam"?

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Q. If a volume of steam of a given pressure expands isothermally to four volumes, what would be the pressure at the end of expansion?
Q. When saturated steam is admitted to the cylinder of an engine does it remain dry, saturated steam during the periods of admission and exhaust?
Q. Does condensation re-evaporate during the latter part of expansion and also during exhaust?
Q. What advantages are derived from the use of superheated steam?
Q. Name some of the important properties of superheated steam.

PART V.

Q. What limits the power of a locomotive?
Q. Upon what does the steaming capacity of a locomotive boiler depend?
Q. What is the chief value of a large locomotive boiler?
Q. Of what kind are locomotive boilers?
Q. How many classes of locomotive boilers are there?
Q. What sheets form the outside shell of a boiler?
Q. What sheets form the firebox?
Q. How are the sheets fastened together?
Q. In what direction are stresses exerted by steam pressure?
Q. What prevents the tube sheets from being bulged out in the center?
Q. Of what type are locomotive boilers? Describe each type.
Q. Of what type are locomotive fireboxes? Describe each type.
Q. Describe the different "courses" of a boiler shell.
Q. Describe the different "sheets" of a boiler shell.
Q. Where is the "hip joint"?
Q. What are stay bolts used for?
Q. What is a flexible stay bolt?
Q. Where are the back head braces?
Q. What are the safety valves for?
Q. Why are two or more safety valves used on locomotive boilers?
Q. Describe a steam gauge.
Q. In connection with the term "draft," explain how motion of a gas is produced.
Q. What functions does the smokestack perform?
Q. Describe the deflector plate and its use.
Q. What is the exhaust nozzle for?
Q. What effect will a small exhaust nozzle have on the fire and also the working of the engine?
Q. What is the blower for?
Q. What types of superheaters are in use?
Q. What type is used for producing high degree of superheat? Of low degree superheat?
Q. What is boiler horse power?
Q. How is heating surface measured?
Q. Describe how an injector forces water into a boiler.
Q. How many classes of injectors are there?
Q. What is important to keep an injector working properly?
Q. How is an injector used as a heater?
Q. To insure the successful operation of a heater, is it necessary to have circulation and drainage? Why?
Q. If it is impossible to obtain circulation and drainage, what should the engineman do to prevent the pipes and hose from freezing?
Q. What may be wrong with an injector when it will not prime?
Q. What should be done when the water in the supply pipe becomes hot?

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Q. What may be wrong when an injector will not force water after priming?
Q. Will an injector take water from the tank if the air cannot get into the tank as fast as the water goes out?

PART VI.

Q. What is Lubrication?
Q. Is fuel economy effected by proper lubrication?
Q. What kinds of lubricants are generally used?
Q. What precautions should be taken when oiling with the view of effecting economy?
Q. How should driving or engine truck box cellars be packed?
Q. What precautions should be taken when placing oil on top of driving and engine truck boxes?
Q. Does it impair the lubricating properties of machinery oil to carry it in such location on the locomotive that it will be heated to a *high* temperature?
Q. How should the plunger in a grease cup be adjusted?
Q. What device is used when driving journal is lubricated with grease?
Q. What parts adjacent to the driving boxes should be oiled when driving journals are lubricated with grease?
Q. How often should engineers examine indicator rods on grease boxes?
Q. What is a sight-feed lubricator?
Q. Upon what principle does it work?
Q. What are the principal parts of a lubricator?
Q. What function does each part perform?
Q. What may cause a decrease in the rate of feeding oil?
Q. How may these defects be remedied?
Q. What may cause an irregular rate of feeding oil?
Q. How may this be remedied?
Q. What may cause an increase in rate of feed?
Q. How may this be remedied?
Q. What will be the effect of a loose oil tube?
Q. What will cause a loss of oil?
Q. What defects will make filling of lubricator difficult?
Q. How should a lubricator be filled?
Q. What should be done when there is not sufficient oil to fill the lubricator?
Q. What valve should be opened immediately after filling a lubricator? Why?
Q. How should feeds be adjusted? On compound locomotives?
Q. Should both the steam and condensing valves be fully or partly open when the lubricator is in operation?

PART VII.

Q. What is meant by the term "Valve Gear"?
Q. What admits steam to and exhausts it from the cylinders of a locomotive?
Q. What are the most prominent types of valve gear in use?
Q. What is meant by "Inside Gear"? "Outside Gear"?
Q. What advantages are obtained by using outside gear?
Q. What is meant by "Direct Motion"? "Indirect Motion"?
Q. What is meant by "Outside Admission"? "Inside Admission"?
Q. Name the different kinds of valves.

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Q. Do slide valves have inside or outside admission?
Q. Do piston valves have inside or outside admission or both?
Q. What is the reverse lever used for?
Q. What is meant by the term "Admission"?
Q. What is "Angular Advance"?
Q. What is meant by "Cut-off"?
Q. What is "Compression"?
Q. What is meant by "Distribution of Steam"?
Q. What is meant by "Release or Exhaust"?
Q. What is meant by "Expansion"?
Q. What is "Inside Clearance"?
Q. What is "Lap"?
Q. What is "Inside Lap"?
Q. What is "Lead"?
Q. What is meant by "Pre-admission"?
Q. What is "Travel"?

PART VIII.

Q. What are the engineers' and firemen's first duties on reporting at the engine house?
Q. When taking charge of a locomotive what should engineers first observe?
Q. What should the engineer inspect as to equipment?
Q. Is it important to have all the gauge cocks in working order?
Q. What is the proper method of blowing out the glass water gauge?
Q. Is it good practice, in cold weather, to heat the cylinders gradually?
Q. What should the fireman observe on arrival at the engine assigned to him?
Q. What should be inspected in the firebox?
Q. What should be noted about the safety valves?
Q. What should be noted about the air gauges?
Q. Should both injectors be tried?
Q. When it is known the fire is to be drawn and pressure blown off boiler at end of trips, what should be reported if necessary?
Q. What should hand railings, headlights, grabirons, foot boards, running boards, steps and safety appliances be inspected for?
Q. What should be inspected about couplers and pilot?
Q. What should be inspected about the sanding apparatus?
Q. What should be inspected about engine truck wheels and driving wheels?
Q. What should be inspected about engine frames?
Q. What should be inspected about expansion pads and braces?
Q. What should be inspected about main and side rods?
Q. What should be inspected about crossheads and guides?
Q. What should be inspected about the cylinders?
Q. When inspecting bolts what should be noted?
Q. What should be inspected about driving boxes?
Q. What should be inspected about valve gear?
Q. What should be inspected about the spring rigging?
Q. What should be inspected between engine and tender?
Q. What should be inspected about the smoke box?
Q. What should be inspected about the pipes and hose?
Q. What should be inspected about ash pan and grates?
Q. After making inspection, what important duty have enginemen to perform at the end of trip?

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Q. When two or more engines are coupled to a train, which one should be started first?
Q. What is the effect of sanding the rail while engine is slipping, without first shutting off steam?
Q. Is it good policy to allow sand to run from one pipe only?
Q. How does the point of cut-off affect coal consumption?
Q. What should be done after stopping heavy trains at stations?
Q. Is it important to avoid sudden variations in temperature in the boiler?
Q. Is there any advantage in having the boiler moderately full when pulling out of a station or when starting a hard pull for a hill?
Q. How should the boiler be fed with water—continuously from beginning to end of trip, or would you shut the injector off when pulling out after each stop?
Q. What is the least amount of water that should be carried in a locomotive boiler under any circumstance?
Q. What is the greatest amount of water that should be carried in the boiler?
Q. How should gauge cocks be used when running?
Q. Should the engineman depend entirely upon the glass water gauge? If not, what should he depend on?
Q. Does water remain at the same level when the throttle is shut off?
Q. What makes a boiler foam?
Q. How do you remedy it?
Q. What is the danger when boiler foams badly?
Q. Is it a good plan to let an engine slip at such times?
Q. Is it liable to break the cylinder packing rings or cylinder heads?
Q. Is any more water used when an engine foams than when water carries well?
Q. What damage does it do to an engine to work water through the cylinders?
Q. When using the surface cock for blowing impurities from the surface of the water in the boiler to what level should the water be blown?
Q. How is the saturated steam superheated after leaving the throttle?
Q. What provision is made for regulating the draft through the large tubes of fire tube superheaters?
Q. What operates the superheater damper?
Q. Is the general operation of superheater locomotives the same as for saturated steam locomotives?
Q. Why is it important to carry the water level at such height that water will not be carried over into the superheater?
Q. Why is it necessary to have air pressure and a good operative brake before moving a superheater locomotive?
Q. Do superheater locomotives require more lubrication than saturated steam locomotives?
Q. Ordinarily how many drops should be fed to the valve chambers and cylinders?
Q. When should the lubricator be started feeding?
Q. Should the throttle valve be completely closed when drifting or approaching points where stops are to be made?
Q. How should a superheater locomotive be fired?
Q. Does the pressure indication on the steam gauge convey any information as to the degree of superheat in the steam?
Q. Describe how you would start a balanced compound locomotive.
Q. How should balanced compounds be operated on descending grades?

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Q. What is important in connection with the manipulation of the reverse lever in order to secure economy of operation of compound locomotives?
Q. Describe how an A. L. Co. Articulated Compound locomotive should be started.
Q. How should this type of locomotive be operated when drifting or descending grades?
Q. What should be done before starting a locomotive under all circumstances?
Q. What should be done in case the water in the boiler becomes low?
Q. What should be done if it becomes necessary to draw the fire on a locomotive that has to be moved or stand in unprotected place during cold weather?
Q. During cold weather what precautions should be taken in the operating of a locomotive?
Q. What precautions should be taken before leaving an engine at any point?
Q. Explain how you would fire an engine to make her steam well, run light on coal, and avoid unnecessary smoke.
Q. What is the cause of the emission of an excessive amount of black smoke?
Q. Which is the proper method of applying fuel to the fire—in large or small quantities?
Q. What kind of a fire should be carried whenever possible?
Q. What should be done just before the engineman closes the throttle at the top of descending grades, or when approaching stations, where stops are made, to prevent smoke from trailing over train when running shut off?
Q. Should the fireman stop firing some time in advance of the engineer closing the throttle?
Q. Will the cold air mix with the gases from the coal and burn at once, or must it be heated first?
Q. Will enough air come through the grates and fire to form perfect combustion of the coal?
Q. Is it necessary to admit any air above the fire?
Q. What effect does it have upon the fire to open the firebox door when the engine is working?
Q. What effect does wetting the coal have?
Q. Is there any economy effected by not wasting steam at the safety valve?
Q. When and how should the grates be shaken?
Q. In what condition should the fire be on arrival at terminals or ash pits?
Q. What is the effect of dead spots in the fire when the engine is running with the throttle closed?

PART IX.

Q. Name some of the causes for pounds about locomotives.
Q. Where should the crank pin of a locomotive be placed in order to test for pounds?
Q. (*a*) Where are the wedges located? (*b*) What are their functions?
Q. How should a pound in a locomotive be located?
Q. If pound is in the rods, can it always be located? How?
Q. Will an engine pound if pedestal bolts are loose? Why?
Q. Name some of the causes for internal blows from locomotives.

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Q. What should be done if a transmission bar or transmission bar hanger should break?
Q. What should be done if a valve should break?
Q. What should be done if a valve seat or valve bushing (piston valve) should break?
Q. What should be done if the reach rod or reverse lever should break?
Q. What should be done if an eccentric rod or straps (Stephenson gear) should break?
Q. What should be done if a valve yoke or valve stem, inside the steam chest, should break?
Q. What should be done if a link hanger, saddle pin or tumbling shaft arm should break?
Q. What should be done if an eccentric crank, eccentric rod, foot of the link, or one of the link trunnions should become disordered? (Walschaerts gear.)
Q. What should be done if a front tire on a 2-6-0 or 2-8-0 type should break?
Q. What should be done if a tire on second driver on a 2-8-0 type should break?
Q. What should be done if a back tire on a 2-6-0 or 2-8-0 type should break?
Q. What should be done if a pony truck center pin or long equalizer should break?
Q. What should be done if either a front or back axle on a 4-4-0 type should break?
Q. What should be done if either a second or a main axle or main tire of a 2-8-0 should break?
Q. What should be done if either a main driving spring or hanger or a back driving spring or hanger on a 4-4-0 type should break?
Q. What should be done if an equalizer on a 4-4-0 type should break?
Q. What should be done if a main driving spring or front driving spring or hanger on a 4-4-2 type should break?
Q. What should be done in case of disorder causing one or more cylinders to become inoperative on American Locomotive Company's articulated compound locomotive?
Q. How should the valve (Walschaerts gear) be blocked to cover ports in case of bent piston rod or cylinder head broken out?
Q. What should be done if the lap and lead lever, lap and lead lever connector or crosshead arm should break?
Q. Explain the two ways of blocking the gear and valve in case of disorder (Baker valve gear).
Q. What should be done if main pin should break?
Q. What should be done if piston rod should break?
Q. What should be done if a guide should break?
Q. What should be done if a cylinder head should break?
Q. What should be done if a side rod or back pin on a 4-4-0 type should break?
Q. What should be done if a side rod or front pin on a 4-4-2 type should break?
Q. What should be done if a back section of side rod on 2-6-0, 2-6-2 or 4-6-2 types should break?
Q. What should be done if a front section of side rod on 2-6-0, 2-6-2 or 4-6-2 types should break?
Q. What should be done if a front or back section of side rod on a 2-8-0 or 2-8-2 type should break?

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Q. How should a test be conducted in order to locate internal blows?
Q. What important duty should engineers perform when accidents or breakage of locomotives necessitate removal of parts?
Q. What should be done if an intermediate or middle section of side rod on a 2-8-0 or 2-8-2 type should break?
Q. What should be done if a front or back tire on a 4-4-0 type should break?
Q. What should be done if either a front or main tire on a 4-4-2 type should break?

PART X.

Q. How should a Sellers Self-acting Injector be operated?
Q. How should a Sellers Non-lifting Injector be operated?
Q. How should a Nathan Non-lifting Injector be operated?
Q. What should be done if the water inlet valve of Simplex Injector leaks, preventing the prompt lifting of feed water?
Q. How should a Nathan Non-lifting Injector be operated?
Q. How should an "Ohio" Lifting Injector be operated?
Q. How should an "Ohio" Lifting Injector be operated to use as a heater?
Q. How should a Chicago Standard "R" Non-lifting Injector be operated?
Q. How should a Chicago Standard "R" Non-lifting Injector be operated to use as a heater?

PART XII.

Q. What law fixes the responsibility for the general construction, safe working pressure, inspection and testing of locomotive boilers and their appurtenances?
Q. What is the lowest factor of safety for locomotive boilers permitted by law?
Q. What is the tensile strength of steel boiler plate? Tensile strength of wrought iron boiler plate?
Q. How often must stay bolts be tested?
Q. How often must steam gauges be tested?
Q. Where should the metal badge plate, showing the allowed steam pressure, be attached to the boiler?
Q. How often should the spindles of all gauge cocks and glass water gauge cocks be removed and cleaned of scale and sediment?
Q. Is it permissible for gauge cocks to be in such bad order that they cannot be manipulated without the aid of a wrench or other tool?
Q. In case of accident what does the law require?

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PART XII

FEDERAL LAWS

Boiler Law, Safety Appliance Law

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FEDERAL LAWS.

THIS part contains a copy of the Federal Boiler Law, and that portion of the Federal Safety Appliance Law applying to steam locomotives, relating to steps, handholds, running-boards, etc.

FEDERAL BOILER LAW.

The following rules and instructions are effective for the construction, inspection and operation of locomotive boilers throughout the United States, having been approved by the Interstate Commerce Commission, they being so authorized by an act of Congress, approved February 17, 1911.

Rules and Instructions for the Inspection and Testing of Locomotive Boilers and their Appurtenances.

Responsibility for the General Construction and Safe Working Pressure.

The railroad company will be held responsible for the general design and construction of the locomotive boilers under its control. The safe working pressure for each locomotive boiler shall be fixed by the chief mechanical officer of the company or by a competent mechanical engineer under his supervision, after full consideration has been given to the general design, workmanship, age, and condition of the boiler, and shall be determined from the minimum thickness of the shell plates, the lowest tensile strength of the plates, the efficiency of the longitudinal joint, the inside diameter of the course, and the lowest factor of safety allowed.

FACTOR OF SAFETY.

The lowest factor of safety to be used for all locomotives in service or under construction on or before January 1, 1912, will be fixed after investigation and hearing and after the expiration of the time allowed for filing specification cards.

The lowest factor of safety to be used for all locomotive boilers which are constructed after January 1, 1912, shall be 4.

TENSILE STRENGTH OF MATERIAL.

When the tensile strength of steel or wrought-iron shell plates is not known, it shall be taken at 50,000 pounds for steel and 45,000 pounds for wrought-iron.

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SHEARING STRENGTH OF RIVETS.

The maximum shearing strength of rivets per square inch of cross-sectional area in pounds shall be taken as follows:

	Pounds.
Iron rivets in single shear	38,000
Iron rivets in double shear	76,000
Steel rivets in single shear	44,000
Steel rivets in double shear	88,000

A higher shearing strength may be used for rivets when it can be shown by test that the rivet material used is of such quality as to justify a higher allowable shearing strength.

RULES FOR INSPECTION.

The mechanical officer in charge at each point where boiler work is done will be held responsible for the inspection and repair of all locomotive boilers and their appurtenances under his jurisdiction. He must know that all defects disclosed by any inspection are properly repaired before the locomotive is returned to service.

The term inspector as used in these rules and instructions, unless otherwise specified, will be held to mean the railroad company's inspector.

INSPECTION OF INTERIOR OF BOILER.

Time of Inspection.—The interior of every boiler shall be thoroughly inspected before the boiler is put into service, and whenever a sufficient number of flues are removed to allow examination.

Flues to be Removed.—All flues of boilers in service, except as otherwise provided, shall be removed at least once every three years, and a thorough examination shall be made of the entire interior of the boiler. After flues are taken out the inside of the boiler must have the scale removed and be thoroughly cleaned. This period for the removal of flues may be extended upon application if an investigation shows that conditions warrant it.

Method of Inspection.—The entire interior of the boiler must then be examined for cracks, pitting, grooving, or indications of overheating and for damage where mud has collected or heavy scale formed. The edges of plates, all laps, seams, and points where cracks and defects are likely to develop or which an exterior examination may have indicated, must be given an especially minute examination. It must be seen that braces and stays are taut, that pins are properly secured in place, and that each is in condition to support its proportion of the load.

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Repairs.—Any boiler developing cracks in the barrel shall be taken out of service at once, thoroughly repaired, and reported to be in satisfactory condition before it is returned to service.

Lap Joint Seams.—Every boiler having lap joint longitudinal seams without reinforcing plates shall be examined with special care to detect grooving or cracks at the edges of the seams.

Fusible Plugs.—If boilers are equipped with fusible plugs they shall be removed and cleaned of scale at least once every month. Their removal must be noted on the report of inspection.

INSPECTION OF EXTERIOR OF BOILER.

Time of Inspection.—The exterior of every boiler shall be thoroughly inspected before the boiler is put into service, and whenever the jacket and the lagging are removed.

Lagging to be Removed.—The jacket and lagging shall be removed at least once every five years and a thorough inspection made of the entire exterior of the boiler. The jacket and lagging shall also be removed whenever, on account of indications of leaks, the United States inspector or the railroad company's inspector considers it desirable or necessary.

TESTING BOILERS.

Time of Testing.—Every boiler, before being put into service and at least once every twelve months thereafter, shall be subjected to hydrostatic pressure 25 per cent. above the working steam pressure.

Removal of Dome Cap.—The dome cap and throttle standpipe must be removed at the time of making the hydrostatic test and the interior surface and connections of the boiler examined as thoroughly as conditions will permit. In case the boiler can be entered and thoroughly inspected without removing the throttle standpipe the inspector may make the inspection by removing the dome cap only, but the variation from the rule must be noted in the report of inspection.

Witness of Test.—When the test is being made by the railroad company's inspector, an authorized representative of the company, thoroughly familiar with boiler construction, must personally witness the test and thoroughly examine the boiler while under hydrostatic pressure.

Repairs and Steam Test.—When all necessary repairs have been completed, the boiler shall be fired up and the steam pressure raised to not less than the allowed working pressure, and the boiler and appurtenances carefully examined. All cocks, valves, seams, bolts, and rivets must be tight under this pressure and all defects disclosed must be repaired.

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STAY BOLT TESTING.

Time of Testing Rigid Bolts.—All stay bolts shall be tested at least once each month. Stay bolts shall also be tested immediately after every hydrostatic test.

Method of Testing Rigid Bolts.—The inspector must tap each bolt and determine the broken bolts from the sound or the vibration of the sheet. If stay bolt tests are made when the boiler is filled with water, there must be not less than 50 pounds pressure on the boiler. Should the boiler not be under pressure, the test may be made after draining all water from the boiler, in which case the vibration of the sheet will indicate any unsoundness. The latter test is preferable.

Method of Testing Flexible Stay Bolts With Caps.—All flexible stay bolts having caps over the outer ends shall have the caps removed at least once every 18 months and also whenever the United States inspector or the railroad company's inspector considers the removal desirable in order to thoroughly inspect the stay bolts. The firebox sheets should be examined carefully at least once a month to detect any bulging or indications of broken stay bolts.

Method of Testing Flexible Stay Bolts Without Caps.—Flexible stay bolts which do not have caps shall be tested once each month the same as rigid bolts, and in addition shall be tested once each 18 months by means of a plug wrench and a bar, sufficient pressure being applied to determine if the bolt is broken.

Broken Stay Bolts.—No boiler shall be allowed to remain in service when there are two adjacent stay bolts broken or plugged in any part of the firebox or combustion chamber, nor when three or more are broken or plugged in a circle 4 feet in diameter, nor when five or more are broken or plugged in the entire boiler.

Telltale Holes.—All stay bolts shorter than 8 in. applied after July 1, 1911, except flexible bolts, shall have telltale holes three-sixteenths inch in diameter and not less than 1¼ inches deep in the outer end. These holes must be kept open at all times.

All stay bolts shorter than 8 in., except flexible bolts and rigid bolts which are behind frames and braces, shall be drilled when the locomotive is in the shop for heavy repairs, and this work must be completed prior to July 1, 1914.

STEAM GAUGES.

Location of Gauges.—Every boiler shall have at least one steam gauge which will correctly indicate the working pressure. Care must be taken to locate the gauge so that it will be kept reasonably cool, and can be conveniently read by the enginemen.

Siphon.—Every gauge shall have a siphon of ample capacity to prevent steam entering the gauge. The pipe connection shall enter

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the boiler direct, and shall be maintained steam-tight between boiler and gauge.

Time of Testing.—Steam gauges shall be tested at least once every three months and also when any irregularity is reported.

Method of Testing.—Steam gauges shall be compared with an accurate test gauge or dead-weight tester and gauges found inaccurate shall be corrected before being put into service.

Badge Plates.—A metal badge plate showing the allowed steam pressure shall be attached to the boiler head in the cab. If boiler head is lagged, the lagging and jacket shall be cut away so the plate can be seen.

Boiler Number.—The builder's number of the boiler, if known, shall be stamped on the dome. If the builder's number of the boiler can not be obtained, an assigned number which shall be used in making out specification card shall be stamped on dome

SAFETY VALVES.

Number and Capacity.—Every boiler shall be equipped with at least two safety valves, the capacity of which shall be sufficient to prevent, under any conditions of service, an accumulation of pressure more than 5 per cent. above the allowed steam pressure.

Setting of Safety Valves.—Safety valves shall be set by the gauge employed upon the boiler, to pop at pressures not exceeding 6 pounds above the allowed steam pressure, the gauge in all cases to be tested before the safety valves are set or any changes made in the setting. When setting safety valves the water level in the boiler must not be above the highest gauge cock.

Time of Testing.—Safety valves shall be tested under steam at least once every three months, and also when any irregularity is reported.

WATER GLASS AND GAUGE COCKS.

Number and Location.—Every boiler shall be equipped with at least one water glass and three gauge cocks. The lowest gauge cock and the lowest reading of the water glass shall be not less than 3 in. above the highest part of the crown sheet. Locomotives which are not now equipped with water glasses shall have them applied on or before July 1, 1912.

Water Glass Valves.—All water glasses shall be supplied with two valves or shut-off cocks, one at the upper and one at the lower connection to the boiler, and also a drain cock, so constructed and located that they can be easily opened and closed by hand.

Time of Cleaning.—The spindles of all gauge cocks and water

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glass cocks shall be removed and cocks thoroughly cleaned of scale and sediment at least once each month.

All water glasses must be blown out and gauge cocks tested before each trip and gauge cocks must be maintained in such condition that they can be easily opened and closed by hand without the aid of a wrench or other tool.

Water and Lubricator Glass Shields.—All tubular water glasses and lubricator glasses must be equipped with a safe and suitable shield which will prevent the glass from flying in case of breakage, and such shield shall be properly maintained.

Water Glass Lamps.—All water glasses must be supplied with a suitable lamp properly located to enable the engineer to easily see the water in the glass.

INJECTORS.

Injectors must be kept in good condition, free from scale, and must be tested before each trip. Boiler-checks, delivery pipes, feed-water pipes, tank hose and tank valves must be kept in good condition, free from leaks and from foreign substances that would obstruct the flow of water.

FLUE PLUGS.

Flue plugs must be provided with a hole through the center not less than ¾ in. in diameter. When one or more tubes are plugged at both ends the plugs must be tied together by means of a rod not less than ⅝ in. in diameter. Flue plugs must be removed and flues repaired at the first point where such repairs can properly be made.

WASHING BOILERS.

Time of Washing.—All boilers shall be thoroughly washed as often as the water conditions require, but not less frequently than once each month. All boilers shall be considered as having been in continuous service between washouts unless the dates of the days that the boiler was out of service are properly certified on washout reports and the report of inspection.

Plugs To Be Removed.—When boilers are washed, all washout, arch, and water bar plugs must be removed.

Water Tubes.—Special attention must be given the arch and water bar tubes to see that they are free from scale and sediment.

Office Record.—An accurate record of all locomotive boiler washouts shall be kept in the office of the railroad company. The following information must be entered on the day that the boiler is washed:

(a) Number of locomotive.

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(b) Date of washout.
(c) Signature of boiler washer or inspector.
(d) Statement that spindles of gauge cocks and water glass cocks were removed and cocks cleaned.
(e) Signature of the boiler inspector, or the employee who removed the spindles and cleaned the cocks.

STEAM LEAKS.

Leaks Under Lagging.—If a serious leak develops under the lagging, an examination must be made and the leak located. If the leak is found to be due to a crack in the shell or to any other defect which may reduce safety, the boiler must be taken out of service at once, thoroughly repaired, and reported to be in satisfactory condition before it is returned to service.

Leaks in Front of Enginemen.—All steam valves, cocks and joints, studs, bolts, and seams shall be kept in such repair that they will not emit steam in front of the enginemen so as to obstruct their vision.

FILING REPORTS.

Report of Inspection.—Not less than once each month and within 10 days after each inspection a report of inspection form No. 1, size 6 by 9 in., shall be filed with the district inspector of locomotive boilers for each locomotive used by railroad company, and a copy shall be filed in the office of the chief mechanical officer having charge of the locomotive.

A copy of the monthly inspection report, Form No. 1, or a quarterly inspection card, Form No. 2, properly filled out, shall be placed under glass in a conspicuous place in the cab of the locomotive before the boiler inspected is put into service.

Not less than once each year and within 10 days after hydrostatic and other required tests have been completed a report of such tests showing general condition of the boiler and repairs made shall be submitted on Form No. 3,[1] size 6 by 9 in., and filed with the district inspector of locomotive boilers, and a copy shall be filed in the office of the chief mechanical officer having charge of the locomotive. The monthly report will not be required for the month in which this report is filed.

Specification Card.—A specification card, size 8 by 10½ in., Form No. 4, containing the results of the calculations made in determining the working pressure and other necessary data, shall be filed in the

[1] Form No. 3 should be printed on yellow paper.

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office of the chief inspector of locomotive boilers, for each locomotive boiler. A copy shall be filed in the office of the chief mechanical officer having charge of the locomotive. Every specification card shall be verified by the oath of the engineer making the calculations, and shall be approved by the chief mechanical officer. These specification cards shall be filed as promptly as thorough examination and accurate calculation will permit. Where accurate drawings of boilers are available, the data for specification card, Form No. 4, may be taken from the drawings, and such specification cards must be completed and forwarded prior to July 1, 1912. Where accurate drawings are not available, the required data must be obtained at the first opportunity when general repairs are made, or when flues are removed. Specification cards must be forwarded within one month after examination has been made, and all examinations must be completed and specification cards filed prior to July 1, 1913, flues being removed if necessary to enable the examination to be made before this date.

ACCIDENT REPORTS.

In the case of an accident resulting from failure, from any cause, of a locomotive boiler, or any of its appurtenances, resulting in serious injury or death to one or more persons, the carrier owning or operating such locomotive shall immediately transmit by wire to the chief inspector of locomotive boilers, at his office in Washington, D. C., a report of such accident, stating the nature of the accident, the place at which it occurred, as well as where the locomotive may be inspected, which wire shall be immediately confirmed by mail, giving a full detailed report of such accident, stating, so far as may be known, the causes, and giving a complete list of the killed or injured.

SAFETY APPLIANCE LAW (ABSTRACT).

STEAM LOCOMOTIVES USED IN ROAD SERVICE.

Tender Sill-steps.

Number: Four (4) on tender.

Dimensions: Bottom tread not less than eight (8) by twelve (12) inches, metal.

(*May have wooden treads.*)

If stirrup-steps are used, clear length of tread shall not be less than ten (10), preferably twelve (12), inches.

Location: One (1) near each corner of tender on sides.

Manner of Application: Tender sill-steps shall be securely fastened with bolts or rivets.

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Pilot Sill-steps.

Number: Two (2).

Dimensions: Tread not less than eight (8) inches in width by ten (10) inches in length, metal.

(*May have wooden treads.*)

Location: One (1) on or near each end of buffer-beam outside of rail and not more than sixteen (16) inches above rail.

Manner of Application: Pilot sill-steps shall be securely fastened with bolts or rivets.

Pilot-beam Handholds.

Number: Two (2).

Dimensions: Minimum diameter, five-eighths (⅝) of an inch, wrought iron or steel.

Minimum clear length, fourteen (14), preferably sixteen (16), inches.

Minimum clearance, two and one-half (2½) inches.

Location: One (1) on each end of buffer-beam.

(*If uncoupling-lever extends across front end of locomotive to within eight* (8) *inches of end of buffer-beam, and is seven-eighths* (⅞) *of an inch or more in diameter, securely fastened, with a clearance of two and one-half* (2½) *inches, it is a handhold*).

Manner of Application: Pilot-beam handholds shall be securely fastened with bolts or rivets.

Side Handholds.

Number: Six (6).

Dimensions: Minimum diameter, if horizontal, five-eighths (⅝) of an inch; if vertical, seven-eighths (⅞) of an inch, wrought iron or steel.

Horizontal, minimum clear length, sixteen (16) inches.

Vertical, clear length equal to approximate height of tank.

Minimum clearance two (2), preferably two and one-half (2½), inches.

Location: Horizontal or vertical: One (1) on each side of tender within six (6) inches of rear or on corner.

One (1) on each side of tender near gangway; one (1) on each side of locomotive at gangway; applied vertically.

Manner of Application: Side-handholds shall be securely fastened with not less than one-half (½) inch bolts or rivets.

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Rear-end Handholds.

Number: Two (2).

Dimensions: Minimum diameter, five-eighths (⅝) of an inch, wrought iron or steel.

Minimum clear length, fourteen (14) inches.

Minimum clearance two (2), pereferably two and one-half (2½), inches.

Location: Horizontal: One (1) near each side of rear of tender on face of end-sill. Clearance of outer end of handhold shall be not more than sixteen (16) inches from side of tender.

Manner of Application: Rear-end handholds shall be securely fastened with not less than one-half (½) inch bolts or rivets.

Uncoupling-levers.

Number: Two (2) double levers, operative from either side.

Dimensions: Rear-end levers shall extend across end of tender with handles not more than twelve (12), preferably nine (9), inches from side of tender with a guard bent on handle to give not less than two (2) inches clearance around handle.

Location: One (1) on rear end of tender and one (1) on front end of locomotive.

Handles of front-end levers shall be not more than twelve (12), preferably nine (9), inches from ends of buffer-beam, and shall be so constructed as to give a minimum clearance of two (2) inches around handle.

Manner of Application: Uncoupling-levers shall be securely fastened with bolts or rivets.

Couplers: Locomotive shall be equipped with automatic couplers at rear end of tender and front of locomotive.

STEAM LOCOMOTIVES USED IN SWITCHING SERVICE.

Footboards.

Number: Two (2) or more.

Dimensions: Minimum width of tread, ten (10) inches, wood.

Minimum thickness of tread, one and one-half (1½), preferably two (2), inches.

Minimum height of back-step, four (4) inches above tread.

Height from top of rail to top of tread, not more than twelve (12) nor less than nine (9) inches.

Location: Ends or sides. If on ends, they shall extend not less than eighteen (18) inches outside of gauge of straight track, and shall be not more than eight (8) inches shorter than buffer-beam at each end.

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Manner of Application: End footboards may be constructed in two (2) sections, *provided* that practically all space on each side of coupler is filled; each section shall be not less than three (3) feet in length.

Footboards shall be securely bolted to two (2) one (1) by four (4) inches metal brackets, *provided* footboard is not cut or notched at any point. If footboard is cut or notched or in two (2) sections, not less than four (4) one (1) by three (3) inches metal brackets shall be used, two (2) located on each side of coupler.

Each bracket shall be securely bolted to buffer-beam, end-sill or tank-frame by not less than two (2) seven-eighths (7/8) inch bolts.

If side footboards are used, a substantial handhold or rail shall be applied not less than thirty (30) inches nor more than sixty (60) inches above tread of footboard.

Sill-steps.

Number: Two (2) or more.

Dimensions: Lower tread of steps shall be not less than eight (8) by twelve (12) inches, metal.

(*May have wooden treads.*)

If stirrup-steps are used clear length of tread shall be not less than ten (10), preferably twelve (12), inches.

Location: One (1) or more on each side at gangway secured to locomotive or tender.

Manner of Application: Sill-steps shall be securely fastened with bolts or rivets.

End Handholds.

Number: Two (2).

Dimensions: Minimum diameter, one (1) inch, wrought iron or steel. Minimum clearance, four (4) inches, *except* at coupler casting or braces, when minimum clearance shall be two (2) inches.

Location: One (1) on pilot buffer-beam; one on rear end of tender, extending across front end of locomotive and rear end of tender. Ends of handholds shall be not more than six (6) inches from ends of buffer-beam or end-sill, securely fastened at ends.

Manner of Application: End-handholds shall be securely fastened with bolts or rivets.

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Side-handholds.

Number: Four (4).

Dimensions: Minimum diameter, seven-eighths (⅞) of an inch, wrought iron or steel. Clear length equal to approximate height of tank.

Minimum clearance two (2), preferably two and one-half (2½), inches.

Location: Vertical. One (1) on each side of tender near front corner; one (1) on each side of locomotive at gangway.

Manner of Application: Side-handholds shall be securely fastened with bolts or rivets.

Uncoupling-levers.

Number: Two (2) double levers, operative from either side.

Dimensions: Handles of front-end levers shall be not more than twelve (12), preferably nine (9), inches from ends of buffer-beam, and shall be so constructed as to give a minimum clearance of two (2) inches around handle.

Rear-end levers shall extend across end of tender with handles not more than twelve (12), preferably nine (9), inches from side of tender, with a guard bent on handle to give not less than two (2) inches clearance around handle.

Location: One (1) on rear end of tender and one (1) on front end of locomotive.

Handrails and Steps for Headlights.

Switching-locomotives with sloping tenders with manhole or headlight located on sloping portion of tender shall be equipped with secure steps and handrail or with platform and handrail leading to such manhole or headlight.

End-ladder Clearance.

No part of locomotive or tender except draft-rigging, coupler and attachments, safety-chains, buffer-block, foot-board, brake-pipe, signal pipe, steam-heat pipe or center arm of uncoupling-lever shall extend to within fourteen (14) inches of a vertical plane passing through the inside face of knuckle when closed with horn of coupler against buffer-block or end-sill.

Couplers: Locomotives shall be equipped with automatic couplers at rear of tender and front of locomotive.

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SPECIFICATIONS COMMON TO ALL STEAM LOCOMOTIVES.

Hand-brakes.

Hand-brakes will not be required on locomotives nor on tenders when attached to locomotives. If tenders are detached from locomotives and used in special service, they shall be equipped with efficient hand-brakes.

Running-boards.

Number: Two (2).

Dimensions: Not less than ten (10) inches wide. If of wood, not less than one and one-half (1½) inches in thickness; if of metal, not less than three-sixteenths (3/16) of an inch, properly supported.

Location: One (1) on each side of boiler extending from cab to front end near pilot-beam.

(*Running boards may be in sections. Flat-top steam chests may form section of running-board.*)

Manner of Application: Running boards shall be securely fastened with bolts, rivets or studs. Locomotives having Wootten type boilers with cab located on top of boiler more than twelve (12) inches forward from boiler-head shall have suitable running-boards running from cab to rear of locomotive, with hand-railings not less than twenty (20) nor more than forty-eight (48) inches above outside edge of running-boards, securely fastened with bolts, rivets or studs.

Handrails.

Number: Two (2) or more.

Dimensions: Not less than one (1) inch in diameter, wrought iron or steel.

Location: One on each side of boiler extending from near cab to near front end of boiler, and extending across front end of boiler not less than twenty-four (24) nor more than sixty-six (66) inches above running-board.

Manner of Application: Handrails shall be securely fastened to boiler.

Tenders of Vanderbilt Type.

Tenders known as the Vanderbilt type shall be equipped with running-boards; one (1) on each side of tender not less than ten (10) inches in width and one on top of tender not less than forty-eight (48) inches in width, extending from coal space to rear of tender.

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There shall be a handrail on each side of top running-board not less than one (1) inch in diameter and not less than twenty (20) inches in height above running-board from coal space to manhole and not less than twelve (12) inches high from manhole to rear of tender.

Ladders shall be applied at forward ends of side running-boards.

Handrails and Steps for Headlights.

Locomotives having headlights which cannot be safely and conveniently reached from pilot-beam or steam chests shall be equipped with secure handrails and steps suitable for the use of men in getting to and from such headlights.

A suitable metal end or side-ladder shall be applied to all tanks more than forty-eight (48) inches in height, measured from the top of end-sill, and securely fastened with bolts or rivets.

Couplers.

Locomotives shall be equipped with automatic couplers at rear of tender and front of locomotive.

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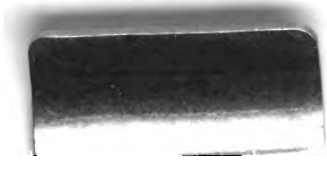

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